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PRODUCTION PROCESS DEVELOPMENT FOR POLYIMIDE-ACRYLIC MATERIALS --ETC(U)

SEP 77 S A HAYS, W A SMITH, F K SAWYER N00123-76-C-0138

UNCLASSIFIED M-24-S-476 NL

1 OF 3

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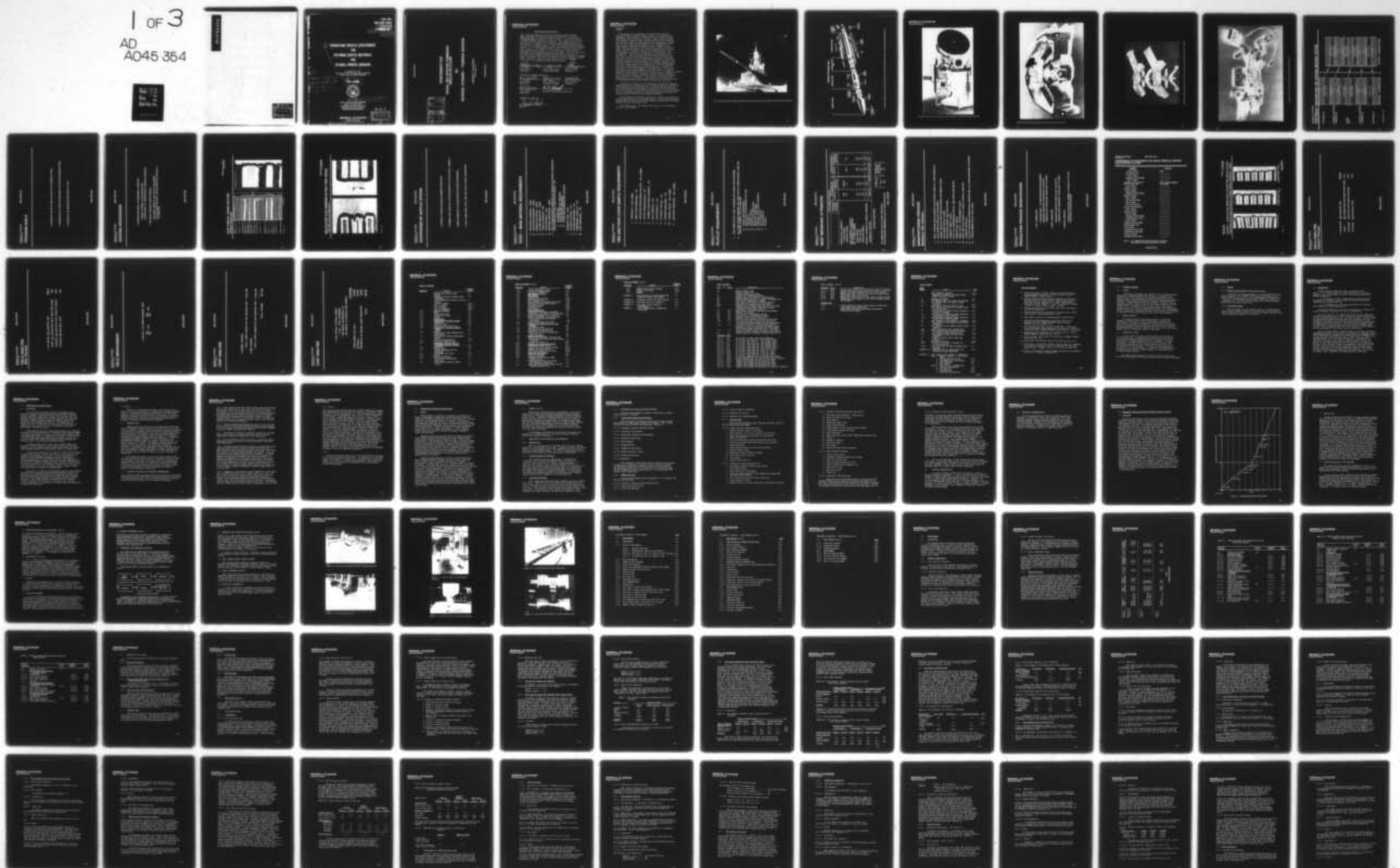

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PRODUCTION PROCESS DEVELOPMENT
FOR
POLYIMIDE-ACRYLIC MATERIALS
FOR
FLEXIBLE PRINTED CIRCUITRY.

A PROJECT OF THE
MANUFACTURING TECHNOLOGY PROGRAM
NAVAL SEA SYSTEMS COMMAND

(10)
Stephen A. / Hays,
Walter A / Smith
F. K. / Sawyer

(9)

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Foreword and Approval Sheet

This is the Final Report for the project performed under contract N00123-76-C-0138, for "Production Process Development for Polyimide-Acrylic Materials for Flexible Printed Circuitry". The Pomona Division of GENERAL DYNAMICS supplied the necessary labor, material, and services which fulfilled the terms of this contract. The cognizant direction was provided by M. C. Abrams, Chief, Advanced Manufacturing Technology, and the Principal Investigator was S. A. Hays, Senior Manufacturing Development Engineer. T. D. Rhoades prepared much of the documentation under direction of W. A. Smith. F. K. Sawyer provided testing. E. Phillips devised the plasma smear removal process. S. A. Hays provided all other process development and directed fabrication of these parts. The work was performed on authorization from Manufacturing Technology Office, Code 0354, Naval Sea Systems Command, contract issued by the Naval Regional Procurement Office, Long Beach, California, and technical direction provided by NAVPRO, Pomona, California, under the cognizant direction of Lt. Commander G. A. Bush. R. M. Bordeaux was the Technical Monitor.

PREPARED BY:

Stephen A. Hays	W. A. Smith	F. K. Sawyer
S. A. Hays	W. A. Smith	F. K. Sawyer
Advanced Mfg. Technology	Power, Distribution & Telemetry Systems	Research & Adv. Techniques

APPROVED FOR GENERAL DYNAMICS BY:

R. W. Aubert	J. A. Thacker	J. H. Rizley
R. W. Aubert	J. A. Thacker	J. H. Rizley
Advanced Mfg. Technology	Power, Distribution & Telemetry Systems	Research & Adv. Techniques
M. C. Abrams	A. T. Winant	
M. C. Abrams, Chief	A. T. Winant, Manager	
Advanced Mfg. Technology	Advanced Manufacturing Engineering	

APPROVED FOR NAVPRO BY:

Gary A. Bush

Lt. Commander G. A. Bush
NAVPRO

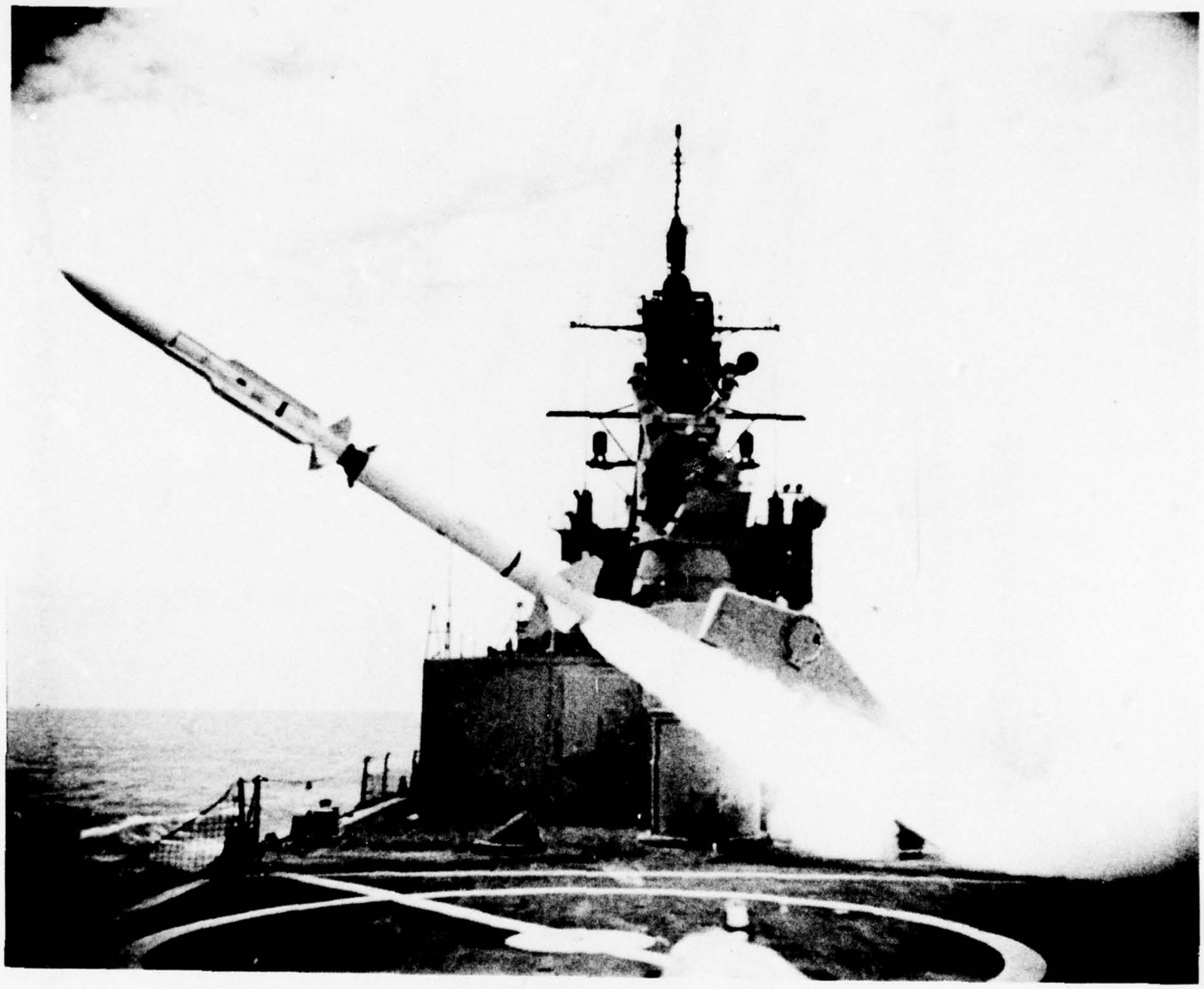
ABSTRACT

The results of a successfully concluded NAV-SEA sponsored program performed by General Dynamics, Pomona, in testing, process development, and fabrication of multilayer Flexible Printed Wiring (FPW) using acrylic adhesive are reported. These acrylic adhesives were obtained in various forms, as copper and/or polyimide laminates and cast film. Based on the findings of this investigation, change-over to these acrylic-polyimide materials is recommended for all continuing FPW fabrication programs, in order to improve yields, improve product reliability, and reduce both processing and overall costs. The program objective of choosing a material/process system which provides a significant reduction in fabrication cost, with an improvement in quality of the product as its acceptance criteria was achieved. This program included testing and fabrication of materials, two layer test pattern FPW, four layer test pattern FPW and a four layer pilot lot FPW consisting of multiple test patterns including an actual tactical missile FPW prototype part. The acrylic materials provided definite advantages over materials in current use, and those known to be currently promising and within the same general cost area. Improvements in peel strength and resistance to thermal shock and flexural fatigue are especially important. Significant achievement in process developments were demonstrated in both plasma smear removal and chromic-phosphoric acid smear removal to provide increased yield and reliability in the critical area of through hole plating. Significant improvements in lamination by vacuum drying of adhesives, and a satisfactory complete multilayer flexible printed wiring process sequence were also established. A 22% reduction in multilayer FPW processing labor costs, and a potential cost savings of $700 per missile in a representative Navy defense missile program, are predicted.

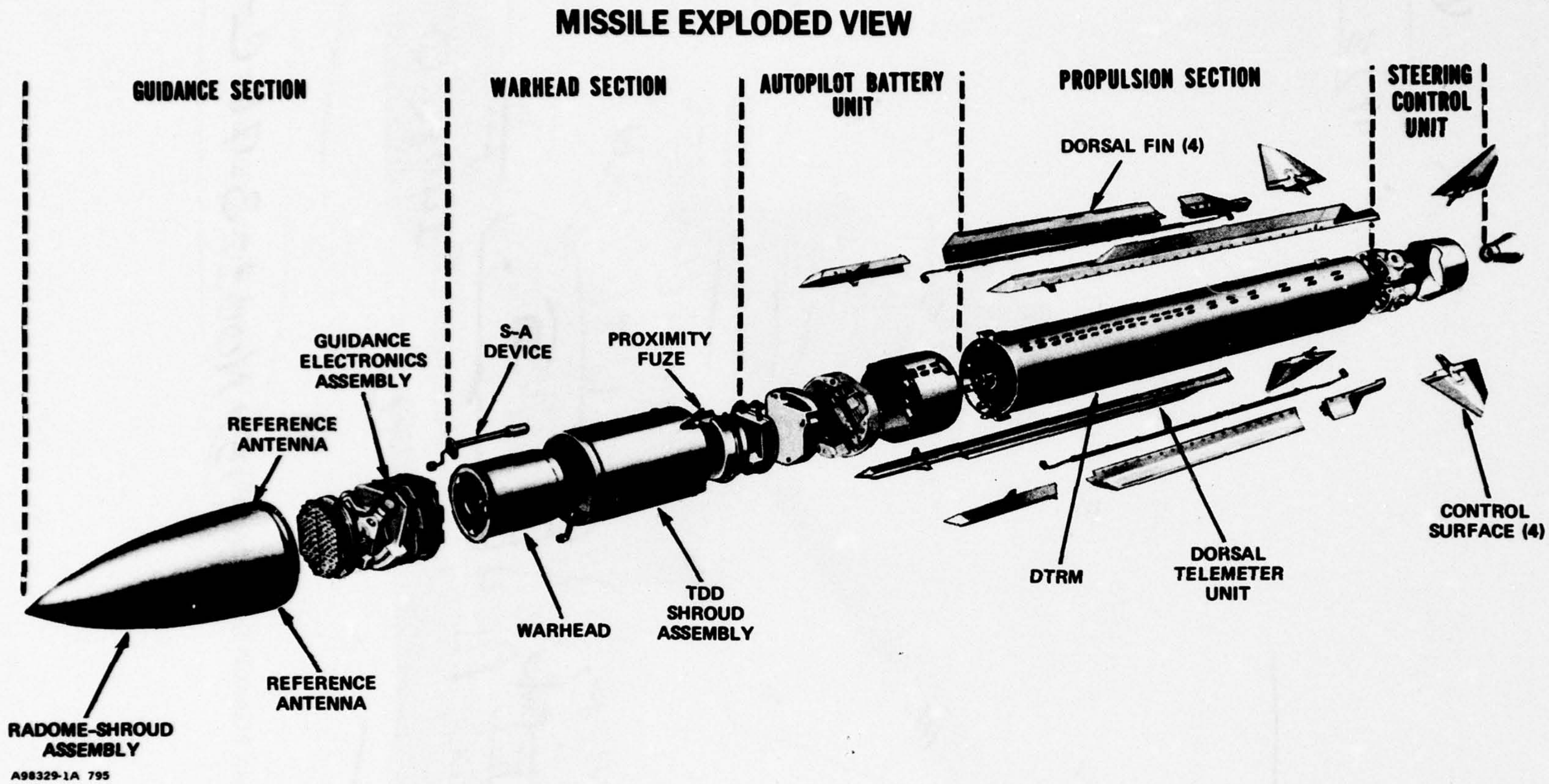
In addition, extensive test and requirement documentation has been established which is valuable for use in future specification and testing of FPW materials and of FPW fabricated for tactical defense products. The increased yield and reliability with reduced cost for multilayer FPW creates an extension of the practical state-of-the-art, which was essential prior to any further progress in increasing interconnection density for flexible printed wiring for future defense electronics.

This program has an immediate application to formal qualification for current Navy programs such as Standard Missile 2 (SM-2), and is presently being proofed on production parts with production documentation for likely incorporation into that product line.

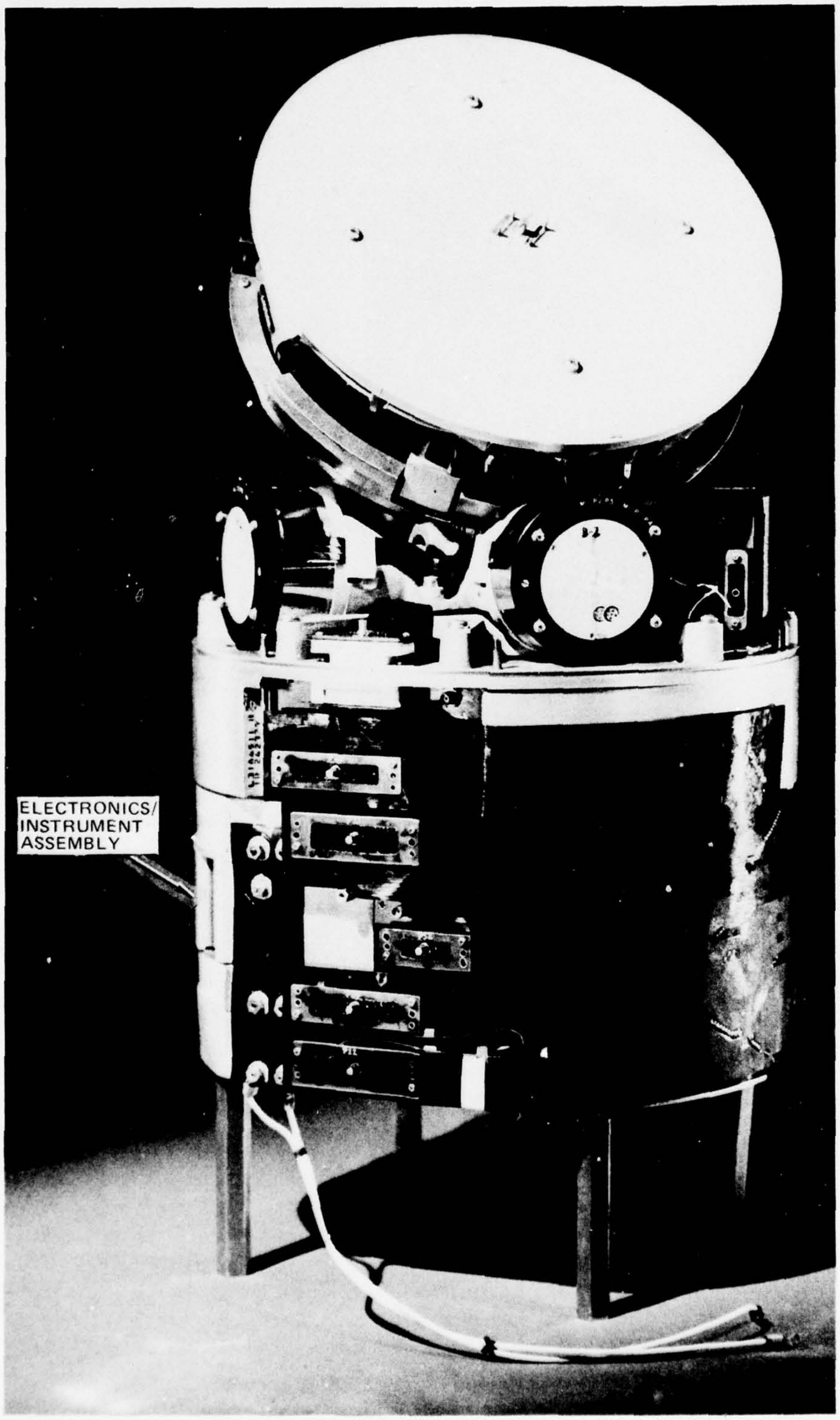
The following pages (iii through xxvii) present a pictorial/chart overview of the program.



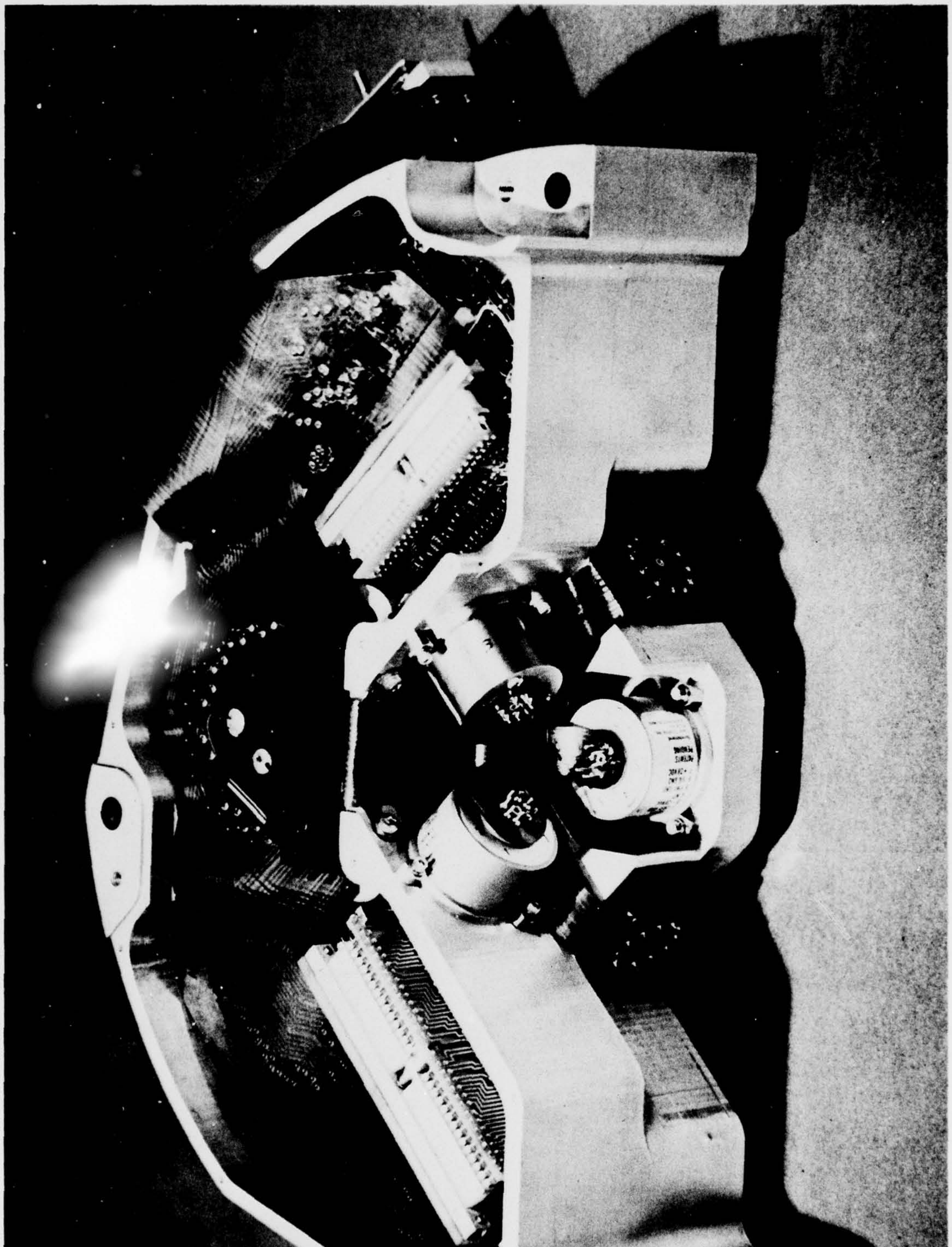
Navy Tactical Defense Missile Deploying Flexible Printed Wiring Guidance Electronic Interconnects



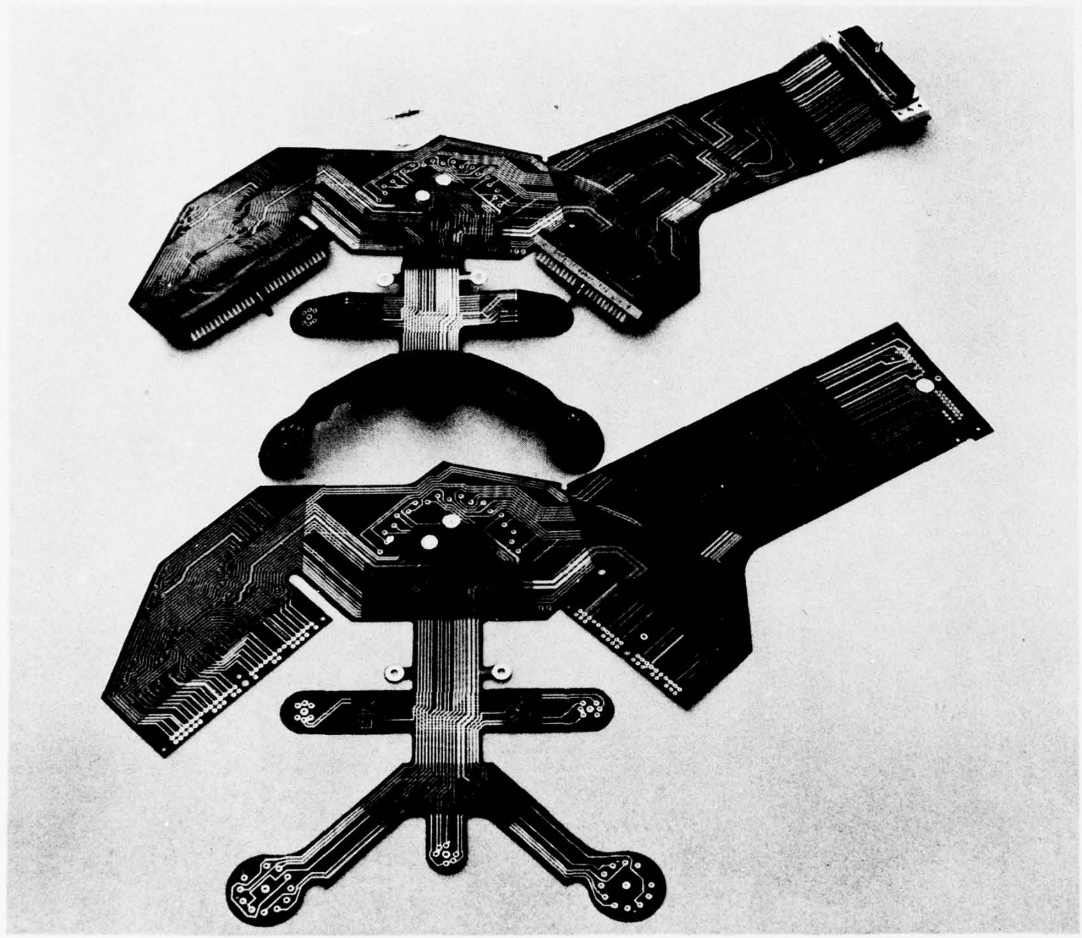
Exposed Guidance and Autopilot Electronics Sections Utilizing Flexible Printed Wiring Interconnects



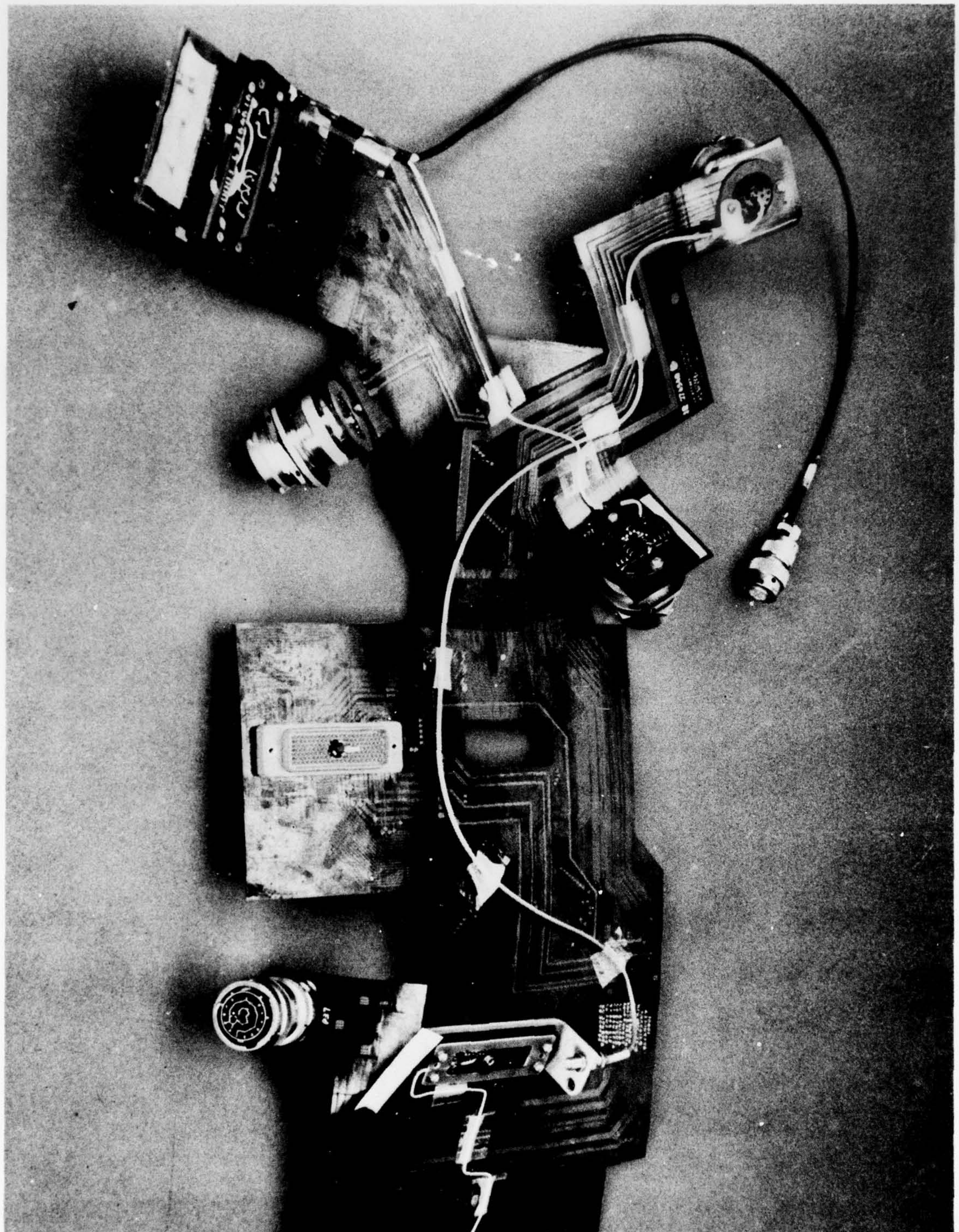
Guidance Electronics Assembly Interconnected by Flexible Printed Wiring



Flexible Printed Wiring Interconnects This Autopilot Assembly



Flexible Printed Wiring as Trimmed, and After Forming and Connector Assembly



Autopilot Flexible Printed Wiring Assembly with Connectors

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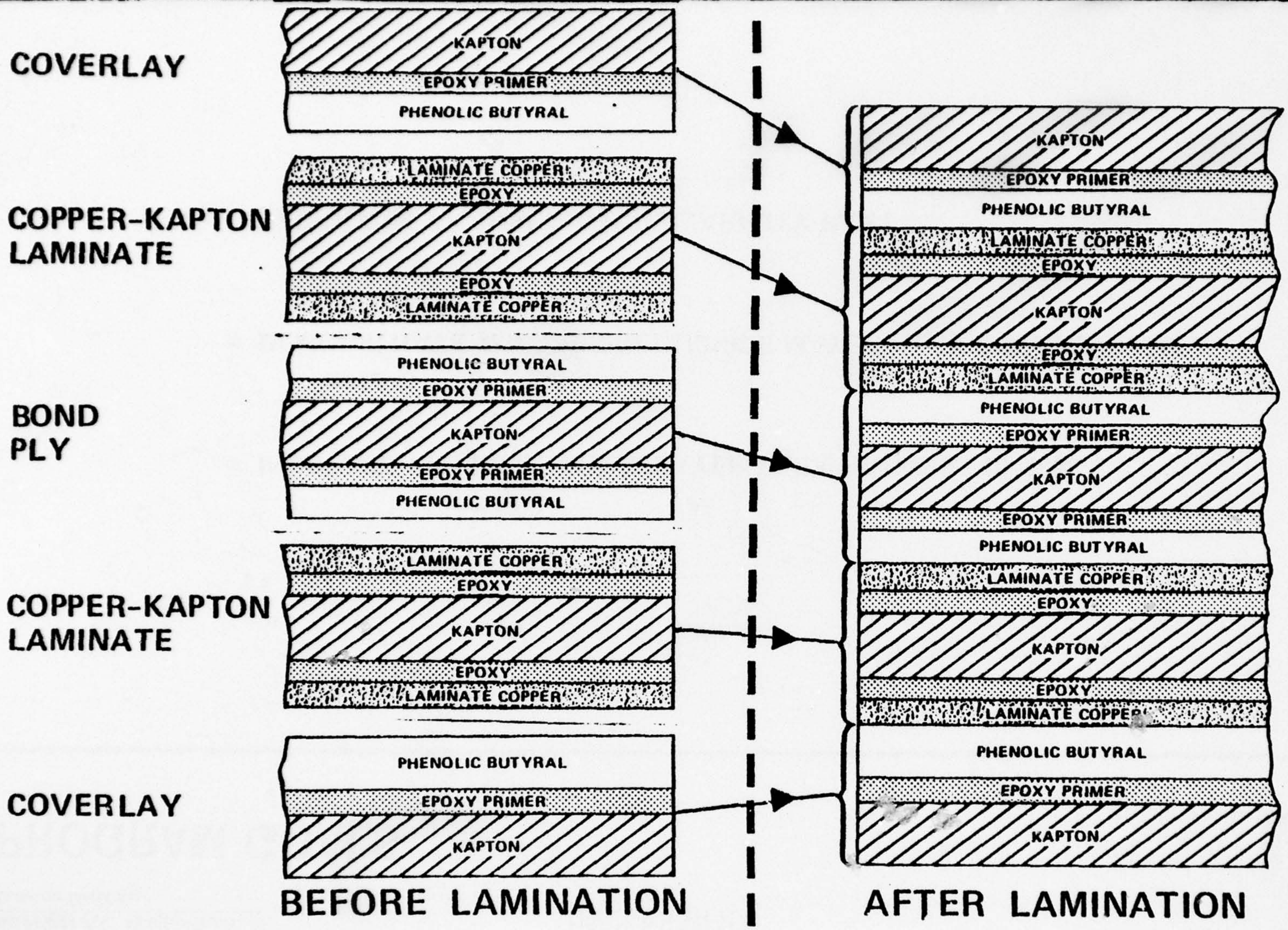
FLEX-CIRCUIT CONSTRUCTION FOR EXISTING MATERIAL SYSTEM



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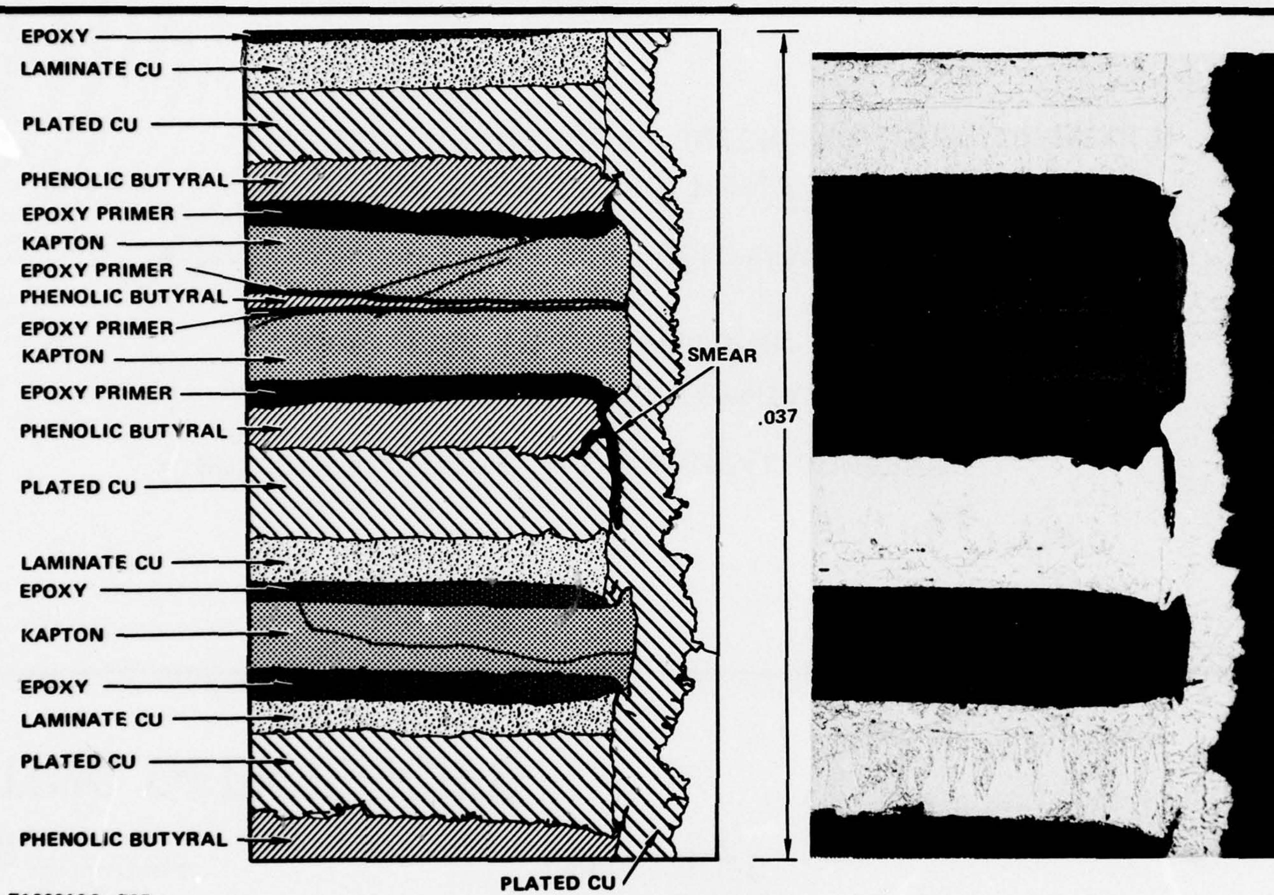
PROGRAM GOALS

- INCREASE YIELDS OF MULTILAYER FLEX HARNESS 10–20%
- DEMONSTRATE A MORE PRODUCIBLE MATERIAL/PROCESS SYSTEM
- FABRICATE AN IMPROVED RELIABILITY PART

EXISTING DEFICIENCIES

- PRESENT MATERIAL HAS MARGINAL ADHESION
  - PRONE TO INNER LAYER SEPARATION
  - SUSCEPTIBLE TO DEGRADATION DURING SOLDERING
- MATERIAL SYSTEM IS VERY COMPLEX
  - REQUIRES COMPLEX MULTISTEP PROCESSING
  - PLATED-THROUGH-HOLE INTERCONNECTOR DIFFICULT TO PRODUCE

FLEX CIRCUIT CROSS SECTION
Present Materials



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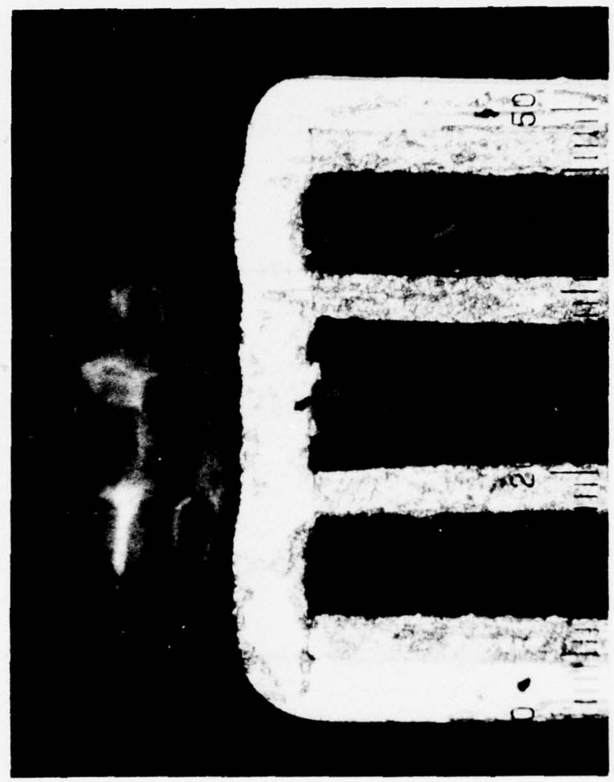
MULTILAYER FLEX HARNESS PLATED THRU HOLES:
"The Bad and the Beautiful"



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ADVANTAGES OF ACRYLIC SYSTEM

- ADHESIVE STRENGTH DOUBLE PRESENT MATERIALS
- NUMBER AND TYPES OF LAYERS REDUCED IN MULTILAYER LAMINATE
- MORE RESISTANT TO DEGRADATION DURING PROCESSING
- VERY COMPATIBLE WITH NEW ONE STEP PLASMA PROCESSING

TESTS — BASIC MATERIAL REQUIREMENTS

A. DIELECTRIC STRENGTH – ASTM

B. DIELECTRIC CONSTANT – ASTM

C. DISSIPATION FACTOR – ASTM

D. VOLUME RESISTIVITY – ASTM

E. TENSILE STRENGTH – IPC

F. TEAR STRENGTH – IPC

G. MOISTURE ABSORPTION – ASTM

H. PEEL STRENGTH WHEN LAMINATED TO UNTREATED COPPER, UNTREATED INSULATION SHEET AND GLASS EPOXY BOARD – IPC

   1. AS LAMINATED
   2. AFTER SOLVENT (6) EXPOSURE
   3. AFTER SOLDER IMMERSION
   4. AFTER HIGH TEMPERATURE EXPOSURE

I. ADHESIVE FLOW – GD/P

J. FLEXURAL FATIGUE – IPC

K. FOLDING ENDURANCE – IPC

L. DIMENSIONAL STABILITY – IPC

M. CURL RESISTANCE – IPC

TWO AND FOUR LAYER SAMPLE REQUIREMENTS

1. CONTINUITY – MIL-P-50884
2. INSULATION RESISTANCE – IPC
3. DIELECTRIC WITHSTANDING VOLTAGE – MIL-P-50884
4. PLATED THROUGH HOLES – IPC
5. TERMINAL AREA BOND STRENGTH – IPC
6. PEEL STRENGTH – IPC
7. SOLDERABILITY – IPC
8. FLEXURAL FATIGUE – IPC
9. FOLDING ENDURANCE – IPC
10. THERMAL SHOCK – MIL-P-50884
11. MOISTURE RESISTANCE – MIL-P-50884

PILOTLOT REQUIREMENTS

1. TEST SAMPLES ARE A SM-2 HARNESS WITH ADDED TEST PATTERNS
2. ALL TESTS BELOW COMPRISE THE FIRST ARTICLE INSPECTION OF, AND ARE FROM MIL-P-50884, TYPE B, CLASS TWO
   - A. VISUAL AND DIMENSIONAL
   - B. DIELECTRIC WITHSTANDING VOLTAGE
   - C. CONTINUITY
   - D. THERMAL SHOCK
   - E. INSULATION RESISTANCE
   - F. MOISTURE RESISTANCE
   - G. TERMINAL AREA BOND STRENGTH
   - H. PEEL STRENGTH
   - I. SOLDERABILITY
   - J. PLATING

MOST IMPORTANT ATTRIBUTES

PEEL/BOND STRENGTH

AVERAGE VALUES IN LBS/IN.	AS LAMINATED		AFTER EXPOSURE	
	ACRYLIC	PHENOLIC BUTYRAL	ACRYLIC	PHENOLIC BUTYRAL
COPPER CLAD LAMINATE				
1" WIDE STRIPS	12.6	8.3(3–5)		
.020 WIDE STRIPS	7.7	5.1	10.6	4.7
CAST ADHESIVE, COVERLAY AND BONDPLY LAMINATED TO: (1" WIDE STRIPS)				
BARE COPPER	6.1	6.2	5.9	5.5
EPOXY GLASS	7.0	4.5	7.7	4.6
BARE POLYIMIDE	5.5	1.2	5.7	1.0
OVERALL AVERAGE OF ABOVE AVERAGES	7.8	5.0	7.5	3.9
COMPOSITE AVERAGE	ACRYLIC = 7.7 PHENOLIC BUTYRAL = 4.5			

SOLDER RESISTANCE

	ACRYLIC	PHENOLIC BUTYRAL
AS LAMINATED (AVG OF OVER 150 PEELS)	6.1	4.3
AFTER SOLDER IMMERSION (AVG OF OVER 20 PEELS)	5.8	2.7

MANUFACTURING PROCESS
Multilayer Flex Harness

1. DRILL TOOLING HOLES (COPPER CLAD KAPTON, BOND PLY, AND COVERLAY)
2. COAT COPPER PANEL/DRY FILM RESIST
3. EXPOSE, DEVELOP AND TOUCH-UP RESIST FOR INNER LAYERS
4. ETCH INNER DETAIL LAYERS
5. STRIP PHOTO RESIST AND CLEAN PANEL
6. LAMINATE INNER LAYERS
7. DRILL ALL TERMINATION, DETAIL, AND FEED-THRU HOLES
8. REMOVE DRILL SMEAR
9. PANEL PLATE – INTERCONNECT HOLES
10. PRINT AND ETCH (STEPS 2-5) ABOVE OUTSIDE CIRCUITRY
11. LAMINATE COVERLAY
12. CUT-OUT OR BLANK PERIMETER OF HARNESS AND ALL OTHER MACHINED FEATURES
13. FORM HARNESS ON ALL FOLD LINES

PRODUCTION PROCESS MODIFICATIONS

- 1ST LAMINATION
  - VACUUM BAKE – AVOIDS MOISTURE ENTRAPMENT
  - PRESSURE REDUCED FROM 650 PSI TO 400 PSI
  - TEMPERATURE INCREASED FROM 340°F TO 380°F
- 2ND LAMINATION
  - PRESSURE REDUCED FROM 700 PSI TO 400 PSI
  - TEMPERATURE INCREASED FROM 340°F TO 380°F
- SMEAR REMOVAL
  - CHANGE 26-STEP WET CHEMICAL PROCESS TO 3-STEP GAS PHASE PLASMA PROCESS

COMPARISON OF PROCESSES FOR SMEAR REMOVAL BEFORE ELECTROLESS PLATING

PRESENT	ACRYLIC
RACK PANELS	SAME
HOT ISOPREP 177	________
SPRAY RINSE	________
RUNNING WATER RINSE	________
SPRAY RINSE	________
CHROMIC ACID ETCHANT (HOT NIKLAD 233P)	DRY PLASMA CHAMBER TREATMENT
SPRAY RINSE	________
UNRACK PANELS	________
SPRAY RINSE	________
RUNNING WATER RINSE	________
RERACK PANELS	________
SPRAY RINSE	________
HOT WATER RINSE	________
SPRAY RINSE	________
HOT WATER RINSE	________
NIKLAD 220 (REDUCER)	________
SPRAY RINSE	________
UNRACK PANELS	________
SPRAY RINSE	________
RUNNING WATER RINSE	________
HYDROCHLORIC ACID	________
SPRAY RINSE	________
RUNNING WATER RINSE	________
CONDITIONER 1160	________
(1-18 HOURS)	________
RUNNING WATER RINSE	________
AUTOMATED RINSE-DRY	________
RERACK PANELS	________
RUNNING WATER RINSE	________

NOTE: ALL REMAINING OPERATIONS ARE STANDARD FOLLOWING ELECTROLESS COPPER PLATING

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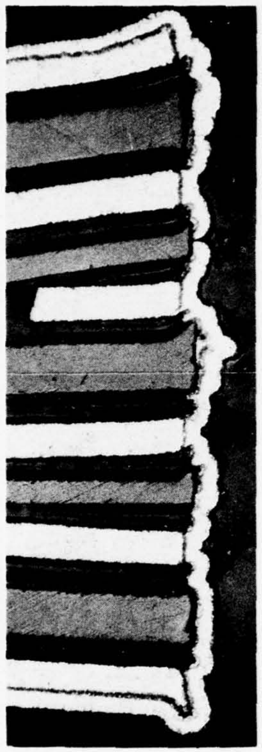
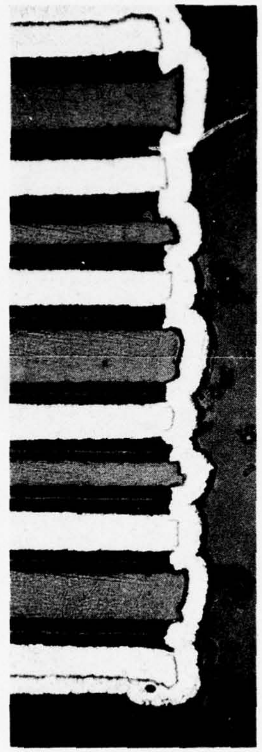
COPPER — ACRYLIC POLYIMIDE MULTILAYER FPW HOLES PLATED THROUGH WITH AND WITHOUT PLASMA SMEAR REMOVAL (200X)



NO TREATMENT
(99)



PLASMA TREATED
(7 MIN AT 40W – TRAY)
(88)

PLASMA TREATED
(2 MIN AT 100W – TRAY)
(97)

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YIELD ANALYSIS
Present Process

• TO OBTAIN	100	ACCEPTED FPW	YIELDS
START	135	LAMINATION SETS RESULTING FROM,	0.74
STARTING	170	DETAIL SETS WHICH REQUIRE,	0.79
STARTING	243	MATERIAL SETS.	0.70

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YIELD ANALYSIS
New Process

• TO OBTAIN 100 ACCEPTED FPW	YIELD
START 115 LAMINATION SETS RESULTING FROM,	0.87
STARTING 128 DETAILED SETS, WHICH REQUIRE,	0.90
STARTING 160 MATERIAL SETS	0.80

YIELD IMPROVEMENT

- 243-160 = 83 FEWER MATERIAL SETS

$$\frac{100}{243} = 41\% \qquad \frac{100}{160} = 63\%$$

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COST ANALYSIS

- PRESENT PROCESS
  - TOTAL LABOR HOURS PER 100 ACCEPTED FPW = 2,704 HRS
- NEW PROCESS
  - TOTAL LABOR HOURS PER 100 ACCEPTED FPW = 2,146 HRS

TOTAL SAVINGS 558 HRS

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COST ANALYSIS

- FOR TYPICAL TACTICAL MISSILE
  - 11 M.L. F.P.W. HARNESSES
  - 900 MISSILE PRODUCTION LOT
  - 332 MISSILE IS AVERAGE COST MISSILE

	SAVINGS($)
LABOR BASED ON YIELD	273,000
MATERIAL	351,000
ESTIMATED IN PROCESS LABOR REDUCTION	20,000
TOTAL	644,000

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1. Technical Proposal, CPC-3865, "Production Process Development for Polyimide-Acrylic Material Flexible Printed Circuitry", GENERAL DYNAMICS, Pomona Division.
2. Contract N00123-76-C-0138, Industrial Resources and Facilities Division, Naval Sea Systems Command, issued by Navy Regional Procurement Office, Long Beach, Ca., 90801, administered by NRPO, P.O. Box 2505, Pomona, CA. 91766, with technical guidance of NAVPRO at General Dynamics, Pomona, CA.91766.
3. Military Specifications, MIL-P-50884, MIL-P-13949, MIL-STD-202, and CCC-T-191 Method 5762.
4. Industry Specifications, Institute of Printed Circuits, IPC-TM refers herein to Test Methods Manual - 650.
5. ASTM (American Society for Testing Material) specifications.
6. Manufacturing Technology Report, "Multilayer Flex Harness Process", S.A. Hays, GENERAL DYNAMICS, Pomona Division, GDPD-MTR-74/070-2, December 1974.
7. Test and Evaluation Plan, M-24-S-476, CDRL A002. "Production Process Development for Polyimide-Acrylic Materials for Flexible Printed Circuitry", GENERAL DYNAMICS, Pomona Division, October 1975.
8. Requirements and Test Methods, TM 6-133-115,-116,-117, and-120, GENERAL DYNAMICS, Pomona Division, 1975-76.
9. Test Procedures, TM 6-133-128,-164,-168 and-174, GENERAL DYNAMICS, Pomona Division, 1976.
10. Test Reports, TM 6-133-184,-186,-187,-192 and -200, GDP, 1976.
11. Proceedings of the Technical Program, National Electronic Packaging and Production Conference, Session IV, "Electroless Copper Line Simplification", Stephen A. Hays, pp 73-80, Feb. and June 1976.
12. Excerpts from Goverment-Industry Summary Presentation at Washington, D.C., by M. C. Abrams, 16 November 1976.

1.0 PURPOSE OF PROGRAM

1.1 PURPOSE

A technical investigation was conducted, based on newly available materials and advanced manufacturing techniques, to establish and demonstrate a fabrication process for producing multilayer flexible printed wiring. The investigation featured a polyimide-acrylic material system of enhanced adhesive properties compared to present production materials. A manufacturing process was developed, consistent with the designated material, which provided improved photo processing, etching, maskant removal, laminating, drilling, smear removal, and plating process steps. The conduct of the program included a basic engineering materials evaluation, the establishment and proofing of the manufacturing process, evaluation of prototypes produced by this process for acceptance in a military tactical weapon system, and a product cost analysis.

1.2 GENERAL OBJECTIVE

The material process system chosen provides a significant reduction in fabrication cost with an improvement in quality and reliability of the product. The approach toward achieving this goal was to select a material with higher peel strength after thermal shock, develop an adequate fabrication process, and then attempt to simplify and eliminate process steps to reduce the base price of the total process sequence and/or to appreciably increase yield rates.

1.3 LIMITATION TO SCOPE

It is not within the scope of this program to provide any of the following items: 1) Formal material specifications and drawings for procurement (although complete material requirements have been established, no formal documentation will be provided); 2) Material qualification (the FPW materials have been fully evaluated to the established requirements, but no formal qualification of materials and suppliers will be performed); 3) Proofing and implementations of the process in the production mode in conjunction with implementation of these materials into any hardware program; 4) Production of any deliverable system hardware.

The output of this program is a generic production process that has been fully developed and evaluated, through limited hardware fabrication.

1.4 REPORTS

1.4.1 Monthly Progress Reports, A001, Parts I and II

In accordance with the requirements of Contract N00123-76-C-0138, Exhibit "a" therein, and the NAVSEA "Manufacturing Technology, General Monthly Reporting Instructions", and a program schedule extension, Part I and Part II of the Monthly Progress Reports (A001) were submitted on 1 September 1975, and on the 15th of October 1975 and each succeeding month to and including 15 August 1976.

1.4.2 Final Report (A003)

This Final Report per the documents above is a detailed account of the technical program concluded on 31 August 1976, and includes the manufacturing process description, technical development, data evaluation, and cost reduction evaluation of the process.

2.0 INTRODUCTION

Flexible printed wiring (FPW) refers to fabricated parts which: 1) are flexible enough to be bent sufficiently to facilitate assembly or use in applications for which a rigid supporting structure would be inadequate,

2) are "printed" in that a formed pattern provides selective dissemination of multiple electrical paths and functions without the limitations of a discrete wire, and

3) is "wiring" as used for providing electrically conducting paths separated by insulating dielectric.

Such FPW are needed for electrical interconnections in guidance and control electronics for missiles, aircraft, and spacecraft.

The basic objective is to increase the reliability and yield while reducing the processing costs of FPW, to reduce the ultimate defense costs of tactical weapon systems and other electronic equipment. This was sought through improved materials selection based on more thorough test and evaluation of polyimide-acrylic materials which appeared most promising in preliminary descriptions and tests. This Navy-sponsored program provided the opportunity for the thorough testing and process development needed to insure that an appropriate base for a cost effective, reliable material/ process replacement for the present system was established.

With the process proofed, testing completed, and several development improvements achieved, it is now possible to proceed with confidence, towards formal specifications, documentations, qualifications and implementations of these materials and processes for the Production mode on programs such as Standard Missile-2 (SM-2) for Naval defense, and to save money while improving reliability. The military, in addition to the Navy as prime contractor, the other defense services, General Dynamics, industry in general, and the material supplier will all benefit by these developments and tests, since this work is both an advancement for the present and can provide a model for future material upgrading. When some future better material is available, the testing program improvements of this project will make the next upgrading substitution that much easier, so that while the vendor's gain is temporary, the technology gain is permanent.

3.0 CONCLUSIONS AND FUTURE ACTIONS

3.1 CONCLUSIONS

The acrylic materials provide definite advantages over the materials in current use, and those known to be currently promising. The peel strengths as laminated and after solvent exposure, and the terminal area bond strength after repeated soldering operations, are especially superior, while the electrical properties are essentially equivalent. Improved flexural fatigue and reduced adhesive flow provide additional benefits from acrylics. The change from two adhesives to one in the bondply and coverlay greatly simplifies the through hole cross section, which in turn improves the drilling, smear removal, and plating results.

Processing costs have been significantly reduced while improving reliability of plated through holes in multilayer FPW by the development of a plasma smear removal process in a parallel General Dynamics study (with patent application). A comparison of processes in Table XXI shows how three plasma smear removal steps replace twenty six steps from the prior chromic acid smear removal process and the extensive precautions needed to insure against chromium poisoning.

The smear removal by use of this "dry" "plasma" method, which physically somewhat resembles a vacuum baking operation, is even more effective with the polyimide-acrylic system than with the dual adhesive system (phenolic butyral plus epoxy primer) which is in current use.

A satisfactory alternative "wet chemical" method for smear removal and electroless plating of acrylic materials was not available to the industry until devised in this project. The successful method was reported at the 1976 NEPCONs (National Electronic Packaging and Production Conferences) in both California and New York (Reference 11). The wet chemical (modified chromic acid) smear removal method resolves the difficult problems of chromium poisoning and acrylic exudation which prohibited application of prior chromic acid smear removal processes to acrylic materials, but it does not compare with the savings in labor and process control provided by the plasma method.

This project, in addition to successfully testing a newer material for application to flexible printed wiring (including multilayer flex harnesses) also established much better documentation, specification, testing and evaluation procedures than have been heretofore available. This will greatly simplify testing of any promising future material applicants. The incoming material specifications, the continuing "Quality Assurance" test capability for Production parts, and the resultant improvements in reliability, all benefit from the documentation available from this project.

3.1 (Cont'd)

Several of the individual operations in this project were not totally successful, either because of normal deviation among individual results, or experimental fabrication imperfections, but the overall averages of the data, the overall result of the project (in securing adoption of improved materials for lower cost and higher reliability), and the overall process development of improved smear removal and lamination techniques, were all totally successful.

3.2 IMMEDIATE GOALS

Having achieved the objectives of this manufacturing technology process development program, which has proven the desirability of the acrylic-polyimide flex harness lamination materials, and the producibility of the process, the immediate goals for follow-on implementation under production contracts now become; 1) securing the general acceptance of the new materials, 2) achieving a smooth transition into production fabrication of flexible printed wiring with acrylics, 3). expansion of the plasma smear removal capability for full production, 4). the considerable documentation efforts to control the transition by specifications, drawing changes, procurement, planning, material and quality control, etc., and 5). the extension of the materials and process into the more difficult flex-rigid hybrid fabrication capability. "Polishing" of the individual process operations, such as drilling, automatic cleaning, smear removal, plating, and lamination, shall naturally be a continuing operation, as is all technology, but the processing results already are equal to or better than those in current use.

Even though the success of the project and the obvious acrylic advantages shown by the final results do considerably reduce the need for an extensive final report, the mass of test data obtained and the extensive efforts of design, test documentation, process development, fabrication, evaluation and cost analysis performed in this program still justify this rather massive final report. The conduct of the program and the methods of testing and evaluating can serve as a model for future evaluations of this type.

3.3 FOLLOW-UP ACTIVITIES FOR PRODUCTION IMPLEMENTATION

3.3.1 Acrylic-polyimide laminates should be substituted for the present "phenolic butyral plus epoxy primer" polyimide laminates for fabrication of flexible printed wiring. The acrylic materials tested to date are Pyralux materials from DuPont, who also makes the polyimide.

3.3.2 When comparable materials become available from other sources, they should be qualified by a test series devised from the results of this program. Such a series should start with a few of the most economical tests with the greatest importance (which therefore provide the maximum test return) such as peel tests on the vendor laminate. Then tests should continue (unless unfavorable results intervene), leaving the most costly and/or "least likely to fail" tests until the secondary material is very likely to qualify (either as an alternate source or as a preferred replacement).

3.3.3 Selected Manufacturing Engineering personnel must be briefed for the control of the acrylic-polyimide processing, so that they may monitor and improve the progress and results of the materials changes, to provide a smooth transition into Production.

3.3.4 The physical processing and technical control for the plasma smear removal needs to be further exploited to optimize this new approach and to expand the versatility of this application.

3.3.5 Process development should be continued to extend the acrylic advantages to the more difficult fabrication problems of flex-rigid hybrid fabrication.

3.3.6 Process technology should be continued to further improve the individual process steps in flexible printed wiring fabrication. A controlled drill study using existing artwork with the new materials is again justified to further reduce polyimide "nailheading". Print and etch operations and plating deserve further improvements. Print and etch should be the principal remaining source of yield losses after change to the new acrylic materials and plasma smear removal has removed the delamination and through hole plating from their present prominent positions on the list of major failure modes. While the major plating problems of the present will have been greatly reduced by the plasma smear removal, further progress in plating control is still desirable to maintain maximum copper elongation percentages with uniform coverage to permit an increase of flexural fatigue cycles in multilayer FPW.

3.3.7 Expansion of the in-process testing capabilities should follow from the experience gained in this program. Addition of a peel test area in the trim area, with areas of solid copper, wide strips, and narrow strips can provide an improved testing capability related closely to each individual harness processing panel, showing results related to the actual fabrication history of each panel. Improvements could be made in the plated through hole test capability, to incorporate each hole diameter which involves critical plating needs, and to provide

3.3.7 (Cont'd)

both the present post-plating "Analytical Request" sample, and an added post-blanking sample which includes the effects of all handling, coverlay lamination, and even the immersion tin. Such improvements are a trade-off between cost and reliability, and do include a "law of diminishing returns" effect. Since individual drill bits can be faulty, each critical plated through hole diameter is important. Obviously, though, a size representing two hundred holes in one part is more important than a size used only twice. Likewise, the post production part providing advanced test capability on a design fabricated repeatedly would provide more information per dollar than such added test patterns on the twentieth part, if all had the same added test capabilities. Therefore a reasonable compromise might be to reuse the "pilot lot" artwork, with its test patterns already incorporated, frequently in small lots throughout the program. The next step forward would be to add some extra test patterns to any new layout of any especially large and complex multilayer FPW. Then after such parts are die blanked (or otherwise trimmed) the trim area can be submitted to Quality Assurance for confirmation that the "after total processing" peel strength and plated through holes are satisfactory. This even provides an extra check against overetching, since the narrowest lines would lose some peel strength as overetching narrows the supporting base. All of this increases reliability of one of the more advanced products in our missiles, which, in the long run, the defense industry will be delighted to achieve, in spite of some extra testing cost.

3.3.8

Obviously even better materials will be found sometime in the future, and justified for specific design needs. For example, an "all polyimide" system, while expensive in material cost, is already known to have some promise. But these are a future "design generation", and require more development and testing before being designed into current flexible printed wiring hardware.

4.0 DESCRIPTION OF FLEXIBLE PRINTED WIRING

4.1 GENERAL

"Wiring" herein is limited to its electrical connotation as a system or arrangement of electrically conductive paths, insulated electrically by proper separation by air or other dielectric. "Printed" wiring in its broader sense could be any pattern of electrically conductive paths created by any form of printing, which would include silk screening, photodeveloping, roller or flat plate printing, or even stamped die patterns. These use various materials such as conductive inks, conductive films, etched "subtractive" or plated "additive" wiring, metal foils, and metal-clad laminates. In this program, printed wiring processes were restricted to chemical etching of copper clad substrates.

"Flexible" printed wiring (FPW) might be defined very generally as any "printed wiring" product which may be bent readily without destroying the continuity of its conductive paths. There are still varying limits to the minimum bend radii and number of flexural fatigue cycles which any specific flexible printed wiring design, fabrication materials,and process will withstand. However, this program has a specific objective of reducing cost and/or increasing reliability for a real product, rather than for an entire spectrum within a definition. Therefore the most practical materials, parameters, and processes presently known for fabrication of the flexible printed wiring used for interconnection among components of a typical military tactical weapons system were selected.

Flexible printed wiring for electrical interconnections have been an important production product for several years, replacing mazes of "hard wiring" for assembly simplification, neatness, maintainability, and reliability, all of which are crucial in military electronics. The FPW provide electronic assemblies with lower weight and requiring less space than the wiring systems which they have replaced. Results are much more repeatable. The electrical testing and error correction is faster and more reproducible with documented printed wiring than with bundles of discrete or individual wires subject to human error in assembly, with the errors increasing directly with the complexity of modern weapons. The FPW are less expensive for complex assemblies, and are especially so as complexity increases. The FPW are more reliable, due to the fixed and reproducible spatial relationships between electrical circuits within the assembly, based on actual experience with weapon system reliability data, and due to fewer human errors associated with the reduced assembly joining operations relative to hard wiring.

4.1 GENERAL (Cont'd)

This project maintained most of the parameters of the selected system without change, while developing, demonstrating, and proving feasibility of a fabrication process substituting a different adhesive system (acrylic). Among the unchanged parameters are use of polyimide for the insulating dielectric, and copper for the primary conductor; photoetching of copper-clad laminate and use of copper plated through holes for interconnections between layers; use of double-sided laminates with one ounce copper before plating, .001 inch adhesive thickness throughout, with .002 inch thick polyimide in the clad laminate, but with .001 inch polyimide with adhesive on either one side for coverlay or on both sides for bondply.

The advantages established for this material system under this program can be implemented over a wide range of products requiring military Specification performance.

4.2 DESCRIPTION OF BASIC MATERIALS FOR FABRICATION

4.2.1 <u>Adhesive Film</u>

This is a modified acrylic film, about .001 inch thick, normally supplied on a release sheet in roll form. A common roll width is 24 inches. Actually, the bare adhesive film is not required for either two layer or multilayer flexible printed wiring. It is still a basic material, and has been used in some flexible and flex-rigid hybrid printed wiring.

4.2.2 <u>Insulation Sheet With Adhesive</u>

This includes two product applications. Polyimide film (insulation) .001 inch thick has adhesive either on one side (for "coverlay" used for external cover sheets to insulate against electrical short circuits, and to provide corrosion protection) or both sides (for "bondply" commonly used for lamination of, and electrical insulation between two adjacent etched copper layers in a multilayer). This program was limited to four layer multilayers, which require only one bondply layer between two double-clad laminates. In this program, each double-clad laminate was etched (on the side which will become an internal layer) prior to lamination of the multilayer FPW.

4.2.3 <u>Copper-Clad Laminates</u>

This program used double-clad copper laminates currently available from vendors. These have "one ounce" copper, which averages .0014 inch thick, on both sides of .002 inch thick polyimide, with an adhesive layer of about .001 inch thickness on each side of the polyimide (between it and the copper). Both the copper and the polyimide are usually treated by the vendor prior to lamination to improve adhesion peel strength. Other thicknesses of copper, polyimide, and adhesive are readily available.

4.3 DESCRIPTION OF TYPICAL FABRICATION PROCESS

The basic steps presently included in fabrication of flexible printed wiring are as follows:

4.3.1 Single Layer Flexible Printed Wiring

The basic material evaluation requires peel testing of copper lines etched on a single layer of copper clad laminate. This involves the first few steps of typical FPW processing. These are:

4.3.1.1 Cutting and Sizing of Individual Layers

4.3.1.2 Cleaning of Clad Laminate

4.3.1.3 Drying and/or Baking of Clad Laminates

4.3.1.4 Photoresist Application

4.3.1.5 Photo Exposure

4.3.1.6 Photodeveloping

4.3.1.7 Examination and Touch-Up

4.3.1.8 Chemical Etching of Copper

4.3.1.9 Stripping Photoresist

4.3.1.10 Inspection

This completes a single layer pattern suitable for peel testing of narrow lines. Drilling or punching of holes, conductive coatings for improved solderability or corrosion protection (usually plated), and insulating coatings (such as conformal or coverlay coatings) might also be included for typical single layer FPW, or in double layer FPW without plated through holes.

4.3.2 Double Layer FPW

These use the operations above (paragraph 4.3.1) for single layer FPW, plus the following:

4.3.2.1 Drilling of Tooling and Plated Through Holes

4.3.2.2 Electroless Copper Plating

4.3.2.3 Copper Electroplating

4.3.2.4 Clean and Bake for Lamination

4.3.2.5 Lamination of Coverlay

4.3.2.6 Immersion Tin or Related Coatings

4.3.3 Multilayer FPW

The total MLF fabrication process for four layer FPW is given in the following abbreviated summary.

4.3.3.1 Prepare Two Layer Etched FPW Details.

1. Prepare Planning, Artwork, and Tooling.
2. Gather Materials, Cut to Size, and Stack for Drilling.
3. Drill "Tooling Hole Driller" Holes in Clad Laminates, Bondply and Coverlay.
4. First N/C (Numerically Controlled) Drilling (with tape).
5. Clean and Dry Copper Double Clad Laminates (two per MLF).
6. Apply Photoresist.
7. Expose Internal Layers (One side on both details).
8. Develop Internal Layers.
9. Examine and Touch Up Pattern as Needed.
10. Etch Internal Layer Side Only.
11. Strip Resist.
12. Inspect Etched "Details".

4.3.3.2 Laminate and Process Multilayer FPW

1. Re-assemble Lamination Materials and Tooling.
2. Clean Etched Details.
3. Bake Etched Details and Bondply.
4. Stack and Laminate Materials (with lamination tooling, rubber, and Teflon release sheets).
5. Drill "Multilayer" Entry and Back up Materials.
6. Assemble MLF Drill Stack.
7. Second N/C Drill (with extra "Multilayer" controlled conditions)

4.3.3.2 Laminate and Process Multilayer FPW (Cont'd)

8. Multilayer X-Ray (Optional). Examine Parts.
9. Deburr and Clean for Plating.
10. Smear Removal.
11. Electroless Copper Plate.
12. Copper Electroplating.
13. Submit Sample for Cross Section Analysis Report.
14. Post-Plating Cleaning and Drying.
15. Apply Photoresist.
16. Expose Both Outer Layers (with aligned photo working tools).
17. Develop.
18. Examine and Touch-up.
19. Etch Outer Layers.
20. Strip Resist.
21. Inspect Bare MLF (Without Coverlay).

4.3.3.3 Apply Protective Coatings

1. Coverlay N/C Drilling.
2. Reassemble Lamination Material and Tooling.
3. Clean, Dry and Bake MLF.
4. Stack and Laminate Coverlay to MLF.
5. Clean "Covered" MLF for Immersion Tin.
6. Immersion Tin Plate.
7. Rinse and Dry MLF.
8. Inspect MLF.

4.3.3.4 Discussion of MLF Processing

Fabrication of this multilayer flexible printed wiring (MLF) includes several important additional operations not needed for two layer FPW. These are the multilayer lamination with bondply (including the cleaning and preparation of the material for lamination), drilling of multilayers (which deserve much more care than that needed for two

4.3.3.4 Discussion of MLF Processing (Cont'd)

layer FPW), and the smear removal between drilling and plating (which is essential to remove smear and other debris from drilling, and to insure good "T-joint" plating in the through holes for reliability). An optional X-ray after drilling may be used to confirm layer-to-layer registration of the individual MLF prior to further investment in its fabrication.

MLF also requires use of all of the operations above in both paragraphs 4.3.1 and 4.3.2. The laminated multilayers are thicker and less flexible, therefore easier to handle than the two layer "details" from which they are made. However, in the laminations with rubber pressure sheets, the unetched outer copper layers partially conform around the internal printed wiring patterns, leaving a "raised" circuitry pattern on the surface. The surface may sometimes be even further roughened by plating. This roughness may be reduced somewhat by power polishing, or even more by sanding, though the latter reduces the uniformity of copper thickness. It is also possible to use more adhesive, and less rubber, for lamination, which then requires greater adhesive flow to fill the increased space between circuitry. That space is otherwise partly filled by the rubber conforming around the circuitry. The conforming outer layers do result in less average harness thickness, and therefore greater flexibility, which is frequently valuable. A surface which is not flat does increase the difficulty of precise print and etch operations. This requires extra care in selection of equipment and processes for fine-line circuitry.

For the test conditions of 0.025 inch minimum distance between line centers, on one ounce copper plated to about two ounce total thickness, the surface irregularities of the MLF are the "lesser of two evils" and are quite acceptable. However, they do still require greater care for multilayer than for two layer "print and etch" operations.

4.4 PHYSICAL CHARACTERISTICS

In service, flexible printed wiring is exposed to a number of physical-mechanical environments. It can be loaded in tension, torsion or flexure. It may be folded over very sharp radii, and it may see environments of $-50^{o}F$ to $+160^{o}F$ under varying degrees of humidity. Therefore, the following physical characteristics of the FPW are of importance to its ability to perform under these conditions: 1) tensile strength; 2) moisture resistance; 3) fungus resistance; 4) flexural fatigue resistance; 5) folding endurance; 6) tear strength; 7) peel strength; 8) dimensional stability; 9) thermal shock resistance.

4.5 ELECTRICAL CHARACTERISTICS

Flexible printed wiring is used to interconnect electrical components. It normally is used to distribute and conduct power and lower frequency signals (less than 5 megahertz). It is also sometimes required to provide EMI/RFI protection to the circuits it is distributing. Therefore, the following electrical characteristics of the FPW are considered to be of importance to its proper electrical operation: 1) dielectric strength; 2) dielectric constant; 3) dissipation factor; 4) volume resistivity.

5.0 BACKGROUND, PREVIOUS WORK AND SUPPORTING SECTIONS INVOLVED

5.1 BACKGROUND

The density and number of electronic interconnections has greatly increased in tactical missiles due to increased performance requirements within the same basic volume. A trend curve is presented in Figure 5-1, which depicts the evolution of electronic interconnect type and density of connections since 1950. This analysis shows that in 1950, when 16 gage round wire was used, we could get approximately 125 conductors in 1-square inch (in^2) of cross-sectional area. This progressed to 1964, when 30 gage wire was being used which gave us approximately 775 conductors per square inch cross-section. However, even though 30 gage wire was required because of the number of circuits and the amount of space and weight that was available, it was not a very producible technique. Therefore, when the next missile design was started, and it predictably required more circuits in a smaller space, a new technology was required for a distribution system. We then developed flexible printed circuits. This was first used in 1965 and provided us with approximately 825 conductors per square inch cross section, when 0.050 wide circuits and 0.050 wide clearance between circuits was used. This technology has progressed from the use of narrower circuits and small spaces, through the use of two sided plated through hole flexible printed wiring (FPW) to the present day usage of multilayer, plated through hole FPW with 0.010 inch wide conductors and 0.010 inch wide clearance with 0.025 inch minimum between centers. This has allowed us to progress from approximately 825 conductors per square inch cross-section in 1965 to approximately 10,500 conductors in 1972. It is interesting to note that the change from round wire to FPW did not initially provide any immediate or large increase in the number of conductors (775 versus 825). However, it did provide us with a technology that was capable of being upgraded to provide us with the necessary increase in conductors. In looking at the trend analysis, it is logical to assume that the need to continually increase the density of our distribution system will exist in the coming years.

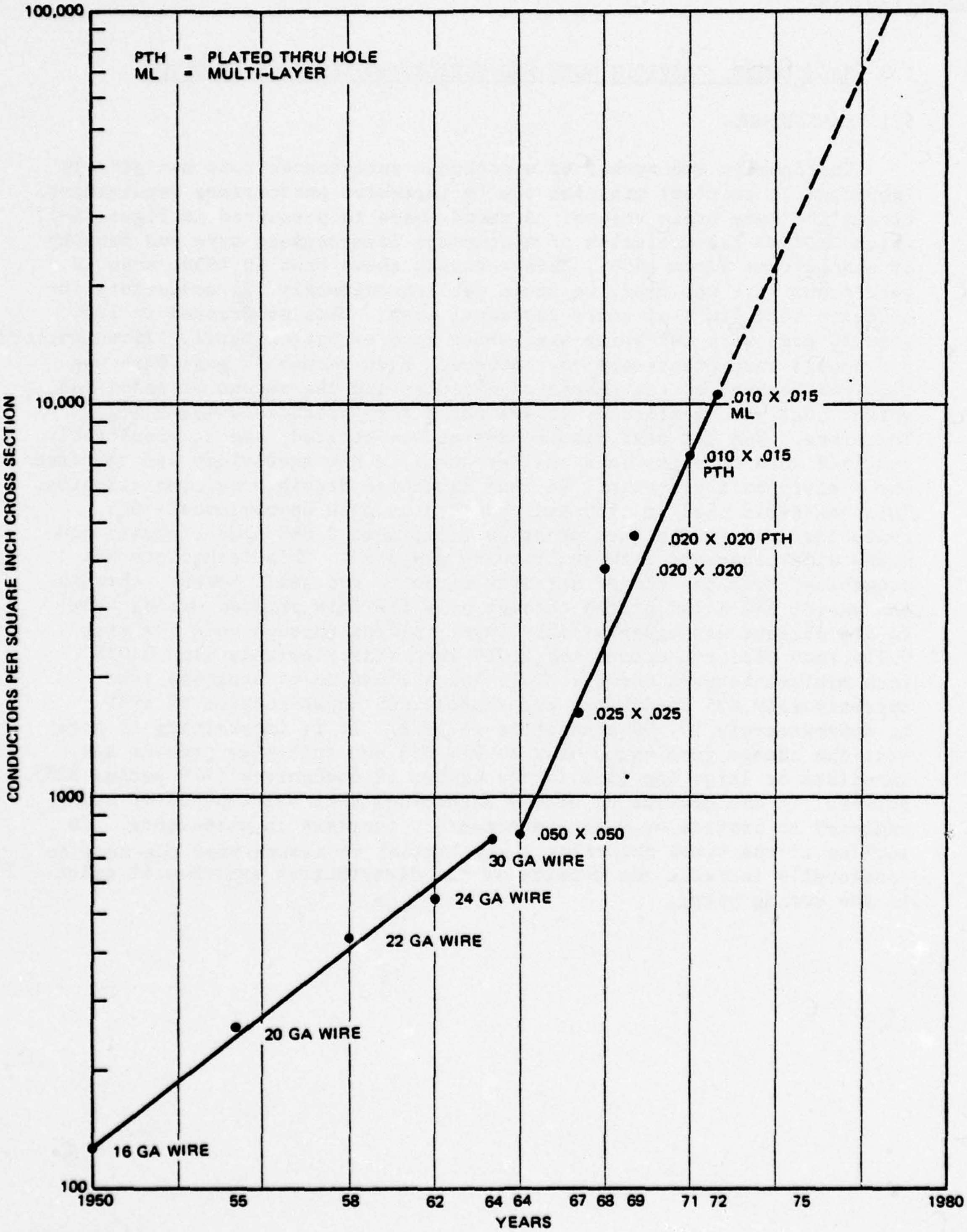

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Figure 5-1. Distribution System Trend Analysis.

5.2 PREVIOUS WORK

In order to provide a cost effective, routine production process that can produce high reliability parts, the manufacturing technology necessary for the production of new designs continues to require breakthroughs over classical rigid circuit board printed circuit fabrication. The materials required to form the interconnect printed circuits, the adhesive layers, and protective cover layers are compromises between the ability to bend and twist and suitability for printed circuit fabrication. Pomona Division pioneered the process development of flexible circuits, with two sides of printed circuitry, each consisting of rolled annealed copper, epoxy-bonded to each side of a polyimide film. This sandwich is from 0.005 to 0.010 inch thick and 4 to 8 inches wide by 6 to 24 inches long. This family of products is presently being produced with high yields in standard production. The evolution of tactical missiles presently in the transformation between engineering design and prototype production are calling for up to four layers of conductive circuitry in a single harness (which corresponds to 17 layers of material) and sizes up to 34 inches long. The density of the circuitry has increased, reducing the printed circuit lines and insulation spaces on each layer from 0.025 to 0.010 inch. Maintaining the required registration from layer to layer, providing adequate bonding between layers, plating through hundreds of interconnect holes (ranging in size from 0.030 to 0.090 inch diameter), and preserving the flexing properties of the harness is a most demanding material - production process. Pomona Division is presently extending the flexible harness multilayer interconnect printed wiring circuitry to meet new requirements.

5.3 PROGRAM RESPONSIBILITY AND MANAGEMENT

This program was under the direct responsibility of Dr. M. C. Abrams, Chief of Advanced Manufacturing Technology. This falls under Manufacturing Engineering, within the Operations Department at the Pomona Division of General Dynamics.

A project team was formed, composed of participants from Advanced Manufacturing Technology and from both the Design and the Materials Research Sections of the Engineering Department. Monitoring the funding, insuring both scheduling and performance, managing the program, and bearing the responsibilities therefore were all a joint effort, directed by M. C. Abrams, supported by J. A. Thacker, Packaging Design, J. H. Rizley, Materials Research, and R. W. Aubert, Advanced Manufacturing Technology. R. W. Aubert oversaw the technical progress.

5.3 PROGRAM RESPONSIBILITY AND MANAGEMENT (Cont'd)

S. A. Hays was the Principal Investigator. Materials Research under direction of J. H. Rizley had the responsibility for the material testing and evaluation (which F. K. Sawyer conducted) and provided the plasma smear removal process devised by E. Phillips in a parallel project. The Packaging Design Section under the direction of J. A. Thacker established the product performance criteria and product evaluation. W. A. Smith was the Responsible Engineer for this activity, with principal support from T. D. Rhoades. All technical direction, progress, and documentation was coordinated with R. M. Bordeaux, Technical Representative for Naval Sea Systems Command, Naval Plant Representative, Pomona, California, under cognizant direction of Lt. Commander D. C. MacDougall, and completed by Lt. Commander G. A. Bush.

5.4 REQUIREMENTS AND DESIGN

W. A . Smith in the Packaging Design Section was the Responsible Engineer for identifying the Engineering requirements for flexible printed wiring. Generation of designs, artwork, and photographic working tools for useful test pattern designs and documentation of the "Requirements and Test Methods", "Test Procedures", and "Test Reports" for single, double, and multilayer flex wiring was included in this section. MIL-P-50884, Institute of Printed Circuits (IPC) and other available standardization of test patterns were used for reference to simplify testing and evaluation. A typical, existing flexible printed wiring design for the pilot lot was also selected by this Design Section.

5.5 TESTING

This activity was conducted by F. K. Sawyer of Material Research. It included coordination with Design to specify the required tests and to identify the test procedures, plus performance of testing, and liaison for Outside Procurement and internal testing support. MIL-P-50884, MIL-STD-202, and IPC specifications were among the references for details of tests.

5.6 PROCESS DEVELOPMENT

S. A. Hays of Advanced Manufacturing Technology was the Principal Investigator for the program. The fabrication process development had to solve all of the requirements for a practical production process to use acrylic-based adhesives for polyimide type flexible printed wiring. Preliminary process studies revealed major differences in satisfactory processing between the single-adhesive system of modified acrylic, and the current materials system which uses epoxy primers and phenolic butyral adhesives. These primarily involved suitable resist stripper selection,

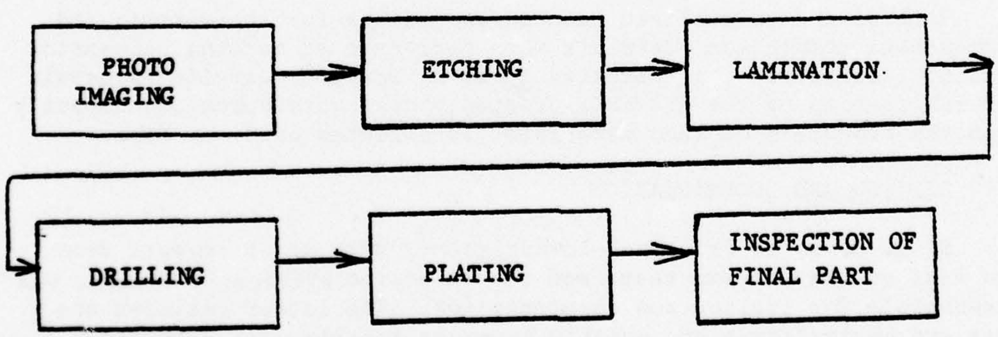
5.6 PROCESS DEVELOPMENT (Cont'd)

modifications in lamination procedures, differences in permissible processing chemicals, and lack of a satisfactory smear removal process which was compatible with through hole plating for acrylic adhesive laminates in the current industry state-of-the-art. Development of pilot plant facilities and application of some Production facilities to the acrylic materials process were also included in this responsibility.

5.7 FABRICATION AND SUPPORTING FACILITIES

S. A. Hays was also responsible for procuring materials and for fabrication of the single, double, and multilayer flexible printed wiring test panels and pilot lot. The prime responsibility for the conduct of the program resided with the Advanced Manufacturing Technology Laboratory. One of the principal functional areas of endeavor within this laboratory is process development for all types of printed circuitry, of which multi-layer flexible printed wiring comprise one of the most significant products.

The principal generic processing steps can be summarized as follows:



Principal Processing Steps

Photographs of the corresponding facilities, all of which exists in the Advanced Manufacturing Technology Laboratories, are presented in Figures 5-2 through 5-7. Figure 5-2 depicts the dry film photo resist roller applicators, the Gyrex light developer table, and the resist stripper tanks, all of which are located in a yellow light room.

5.7 FABRICATION AND SUPPORTING FACILITIES (Cont'd)

Figure 5-3 is a spray etcher with regulated pressure spray nozzles both above and below the work piece. Figure 5-4 illustrates the 300 ton lamination press in the foreground and the 75 ton press in the background. Figure 5-5 shows the precision air driven drill with a wide screen magnification of the optically sighted drill alignment. Figure 5-6 is the automated electroless and electrolytic chemical plating line, with tape programed part sequencing and plating timing. Figure 5-7 is a final multilayer flexible harness, as it appears for inspection.

In addition to these facilities, a completely equipped engineering testing laboratory supports mechanical, electrical, and environmental testing.

5.8 OTHER INTERNAL GENERAL DYNAMICS SUPPORT

This included Quality Assurance, Production, Inspection, Manufacturing Engineering, Purchasing, Production Control, Publication Services, the Producibility and Analysis Group of the Production Yield Analysis Section, and other members of General Dynamics, Pomona.

5.9 OUTSIDE PROCUREMENT SUPPORT

Some of the specialized testing operations for the acrylic and appropriate comparison materials were performed at outside industrial testing laboratories, as directed by F. K. Sawyer. Acrylic materials for fabrication of the flexible printed wiring were purchased directly from the producers of such materials, as directed by S. A. Hays.

5.10 LIAISON AND DOCUMENTATION

S. A. Hays, as Principal Investigator, with major support from the rest of the program team, and the direction previously listed, was responsible for liaison and documentation. The latter includes the test and evaluation plan, monthly progress reports, and this final technical report.

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Figure 5-2. Photo Resist Application and Developing Equipment.

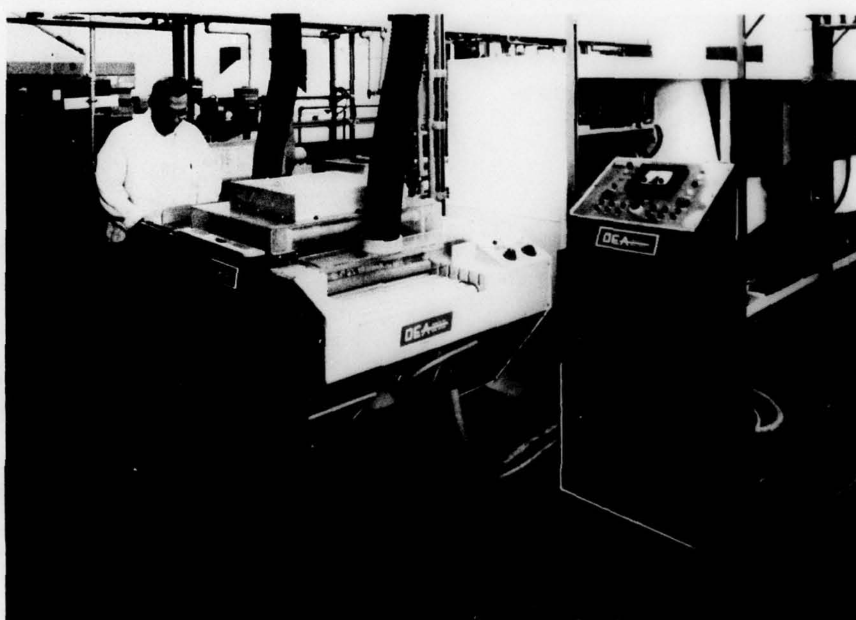

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Figure 5-3. Chemical Spray Etcher.

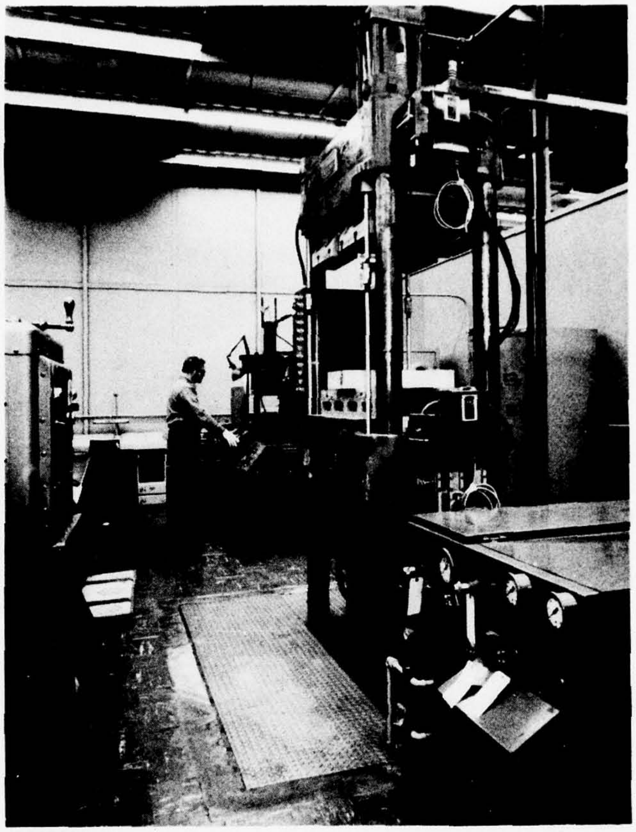

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Figure 5-4. 300 Ton and 75 Ton Compressor Presses.

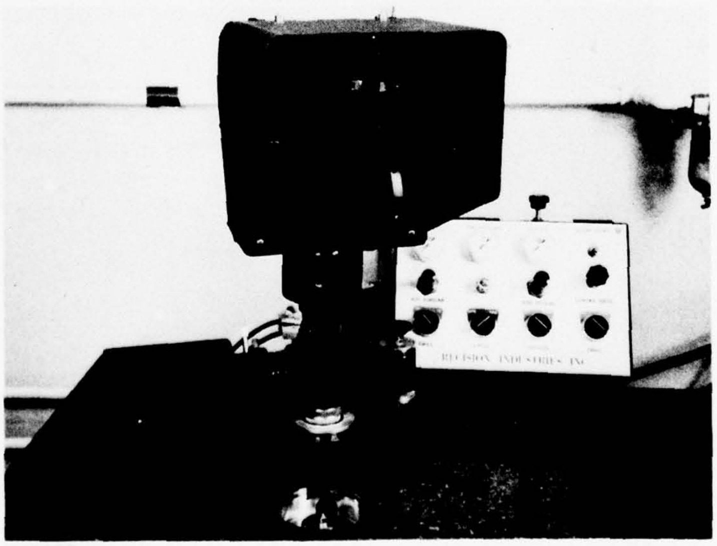

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Figure 5-5. Precision Drill With Optical View Sight.

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Figure 5-6. Automated Circuit Board Plating Line.

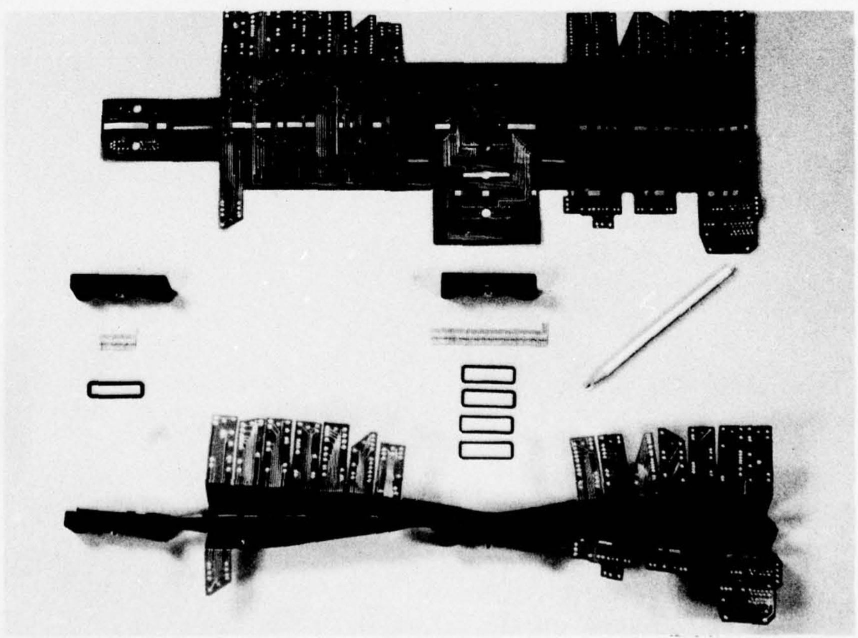

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Figure 5-7. Typical Missile Multilayer Flexible Printed Cable.

SUB-INDEX OF SECTION 6: TEST PROGRAM

SUB-INDEX OF SECTION 6: TEST PROGRAM (Cont'd)

SUB-INDEX OF SECTION 6: TEST PROGRAM (Cont'd)

6.0 TEST PROGRAM (Cont'd)

6.0 TEST PROGRAM

6.1 INTRODUCTION

The expanded test and evaluation procedures as published in "Test and Evaluation Plan", M-24-S-476, are considerably more extensive and elaborate than originally proposed. They are, however, providing a more complete reference criteria than was heretofore available and will provide a valuable base for evaluating future FPW material systems. In addition to being very extensive, the test criteria were refined and limits were re-evaluated as experimental results were obtained.

6.1.1 Material Investigation

6.1.1.1 Basic Material Evaluation

The first step in this program was evaluation of the basic materials that are used to fabricate FPW. This included copper clad laminates, insulation sheet with adhesive and adhesive film.

6.1.1.2 Comparative Materials

The basic intent of this program was to find a material/process system to upgrade multilayer flexible printed wiring products. Although polyimide-acrylic material was recognized early as a prime candidate, other types of materials were evaluated during this phase to provide comparative data for the polyimide-acrylic materials. Some tests were run during this phase to establish what values might normally be expected to be obtainable for certain characteristics of this material.

6.1.1.3 List of Test Materials

Ten materials from three vendors (DuPont, Rexham and Fortin) were submitted for materials tests. These include double clad copper laminates, polyimide insulation sheet with adhesive on either one side (coverlay) or both sides (bondply), and plain adhesive films. For comparative materials evaluations, these represent three different adhesive systems (modified epoxy, phenolic butyral with epoxy primer, and acrylic). Five samples of each of the materials listed in Table I were tested during this phase. Tables II, III and IV provide an index of the materials evaluation tests.

6.1.1.4 Outside Laboratory Test Support

As part of the total material testing per the test plan, samples were submitted to an independent testing laboratory (Delsen Corporation, Glendale, CA.) for measurements of thickness, dielectric strength, breakdown voltage, dielectric constant, dissipation factor, and volume resistivity. Total thickness ranged from one to four mils for different material functions.

6.1.1.5 Types of Adhesives Tested

Since the phenolic butyral with epoxy primer was the adhesive system in current use, primary emphasis was upon a comparison of the proposed acrylic system with the current phenolic butyral system. A second acrylic material source was originally sought, but no other vendor had an acrylic material actually available at the start of this contract. An alternate adhesive system, a modified epoxy, was provided by a third vendor as his best effort. This was included in most (though not all) of the material tests as a partial secondary comparison.

6.1.2 FPW Investigation

Schedule restraints necessitated a parallel effort of acrylic process development during the comparative materials testing. FPW test samples were not prepared for the phenolic butyral system, since sufficient experience seemed available from current Production results, even though not always in quantitative values for precise comparison. FPW were not prepared for the modified epoxy materials, because that was far beyond the scope and budget of this contract, because a comparable process improvement development would not have been available, and finally because the partial materials comparison, though not complete enough to eliminate modified epoxy as a possibility, was still not promising enough to make it the preferred material for further investigation within limited funding. The FPW results are classified separately in the series of "Test Reports" (reference 10) for this program, but those same FPW results are enfolded with the material results and are organized herein according to test title.

MATERIAL	ADHESIVE TYPE	MANU-FACTURER	COPPER THICKNESS	ADHESIVE	DIELECTRIC THICKNESS	ADHESIVE	COPPER THICKNESS
Copper-Clad Laminate:							
	Acrylic	Dupont	1 ounce	Yes	2 mil.	Yes	1 ounce
	Phenolic Butyral	Rexham	1 ounce	Yes	2 mil.	Yes	1 ounce
	Modified Epoxy	Fortin	1 ounce	Yes	2 mil.	Yes	1 ounce
Insulation Sheet:							
	Acrylic	DuPont	None	Yes	1 mil.	Yes	None
	Acrylic	DuPont	None	Yes	1 mil.	None	None
	Phenolic Butyral	Rexham	None	Yes	1 mil.	Yes	None
	Phenolic Butyral	Rexham	None	Yes	2 mil.	None	None
	Modified Epoxy	Fortin	None	Yes	1 mil.	None	None
Adhesive Film:							
	Acrylic	DuPont	None	Yes	None	None	None
	Phenolic Butyral	Rexham	None	Yes	None	None	None

TABLE I

MATERIALS EVALUATED

TABLE II: FLEXIBLE PRINTED WIRING MATERIALS TESTS FOR COPPER CLAD LAMINATE

M24S-476 PARAGRAPH		M24S-476 PAGE	PARAGRAPH HEREIN	PAGE HEREIN
6.1	COPPER CLAD LAMINATE	6-6		
6.1.1	Insulation Sheet			
6.1.1.1	Dielectric Strength		6.7.4	6-76
6.1.1.2	Dielectric Constant		6.7.5	6-78
6.1.1.3	Dissipation Factor		6.7.6	6-80
6.1.1.4	Volume Resistivity		6.7.7	6-82
6.1.1.5	Tensile Strength		6.4.1	6-28
6.1.1.6	Tear Strength, Initial		6.4.2	6-29
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6.2 MATERIALS AND FPW TESTED

The following materials and FPW were the principal categories tested.

6.2.1 Copper Clad Laminates

Polyimide insulation material of 0.002 inch nominal thickness, is clad on both sides with 1 ounce thickness (0.0014 inch) of rolled, annealed copper (treated to promote adhesion) by each vendor using their own proprietary adhesive bonding materials. Similar single clad materials are also available from each vendor, but were not tested, since they should yield comparable test results. These will sometimes be referred to in this report as "treated copper laminates".

6.2.2 Copper Clad Laminate From Which All or Part of the Copper Has Been Etched

Same material as above after copper is etched off, using normal etching techniques, prior to testing. These will be referred to as "etched, treated copper laminates".

6.2.3 Adhesive Coated Insulation Sheets

These are polyimide insulation sheets, of either 0.001 or 0.002 inch nominal thickness, coated on either one side (for use as a coverlay external protective coating for FPW) or both sides (for use as bondply for multilayer FPW laminates) with one or more of the proprietary adhesives by the vendors. However, many tests were duplicated on both coverlay and bondply, for a broader statistical base (for more accurate test results and interpretation) and because of the difference in applications. These will be referred to as "1 mil" or "2 mil" (according to the polyimide thickness) coverlay or bondply.

6.2.4 Adhesive Films

These are cast adhesive films supplied by the different vendors, without any copper or polyimide. Both of those tested in the program were nominally 0.001 inch thick. Although these are no longer used in our present four layer flex harnesses, they are still of interest as a basic material, and are used in some flex-rigid hybrid designs.

6.2.5 Two Layer FPW

Two layer FPW test panels were tested for the requirements below in this section, in accordance with the prescribed test methods. Test results were evaluated by the program team. Any inadequate test results which seem reasonably due to processing methods could be repeated by recycling additional process development and fabrication steps. Any test results which were below desired levels, but which seem realistic, were reported for consideration with other overall results in determining process feasibility.

6.2.6 Multilayer FPW

Multilayer FPW test panels were tested for the requirements below in this section, in accordance with the prescribed test methods. Test results were evaluated by the program team. Any inadequate test results which seem reasonably due to processing methods could be repeated by recycling additional process development and fabrication steps. At least one complete recycle of process development, fabrication, test, and evaluation of multilayer FPW test panels was planned to incorporate development improvements during the program, prior to the pilot lot fabrication. Any test results which were below desired levels, but which seem realistic, were reported for consideration with other overall results in determining process feasibility.

6.2.7 Multilayer Pilot Lot

The Pilot lot was tested by Materials Research for the requirements below in this section, in accordance with the prescribed test methods. In addition, the Design Section arranged for prototype electrical testing which can be compared with results on current Production FPW.

6.3 PEEL STRENGTH TESTS

6.3.1 Introduction

6.3.1.1 Peel Test Matrix Plan

The peel tests may be described as a matrix of three basic adhesive material types (acrylic, phenolic butyral plus epoxy primer, and modified epoxy). Each material type is subjected to nine different pretreatments (as laminated, after immersion in isopropyl alcohol, toluene, methylethyl ketone, 50-50 mixed chlorinated solvents, 2N HCl, 2N NaOH, or molten solder, and after 24 hours baking at 400°F. Each adhesive (within limits of availability at start of testing) was prepared in ten different configurations for test. These are copper

6.3.1.1 Peel Test Matrix Plan (Cont'd)

clad laminate as received, and three sets of bondply, coverlay, or adhesive film, each separately laminated to each of three surfaces (untreated copper, untreated polyimide, or bare epoxyglass). With three to five individual peel tests of each sample type, calculated as an average of four, the total matrix would be four tests times three adhesives times nine pretreatments times ten configurations for a total of 4 x 3 x 9 x 10 = 1,080 peel strength charts. While there are a few gaps in the matrix, over 800 peel test charts were processed.

The peel testing and other material testing data chart recordings were analyzed and converted to individual, numerical data values. These are now recorded onto the corresponding data forms for averaging, statistical analysis, team evaluation, and reporting.

The goals of this study include determination as to which adhesive is best among those currently available for test, and to establish realistic test methods and specification values both for qualifying and for comparing both present and future materials.

6.3.1.2 Present Program

The peel (or bond) strength tests are especially important to FPW because of the extra strains imposed upon flexible printed wiring ("harnesses" or "cables") during bending in assembly and in use, and because of the severe effect of delamination during processing upon plating, etching, and assembly yields. Two types of peel strength tests were used. IPC-TM 650-2.4.9 Method A peels one inch wide cut strips, while Method C (which is more limited in scope but more definitive of certain properties) is not applicable when no copper is included in the laminate. One other hazard of the peel test data is that the polyimide insulation sheet sometimes fails, either by tearing (sometimes at relatively low forces) or by breaking (especially if the polyimide is only 0.001 inch thick). This indicates that the adhesive bond is stronger than the polyimide, although tear and notch effects on the polyimide are frequently involved. Since the breaking occurs if the bond is too strong, while the tearing may occur even with weak bonds, results are questionable when polyimide failures are involved. Even the maximum pull force before breaking is not too significant, since the starting force is frequently considerably greater than the "peel strength" after separation has started.

6.3.1.3 General Suggestions for Future Projects

For future projects, a multiple lamination seems advisable to strengthen the 0.001 inch coverlay materials for peel tests. Adhesion to the surface of an etched and stripped clad laminate, under conditions simulating normal production, is also of interest. Double clad material is first prepared by normal print and etch of a selected pattern, then resist is stripped normally and the etched "detail" is baked at 250°F for one hour. To avoid harmful effects of moisture on either the untreated polyimide coverlay surfaces or the bondply, all acrylic coverlay and bondply should be vacuum baked at 160°F for one hour (at 25 inches of mercury minimum), and kept dry until lamination.

6.3.1.4 Single Lamination for Multiple Tests

It seemed desirable to combine a series of test samples into a single lamination sample to provide maximum correlation among results, to save time, and to strengthen the coverlay.

For example, one sandwich of bondply, coverlay, bondply, partially etched double clad copper laminate, coverlay, and another coverlay (in that order) could provide peel test samples for the following:

6.3.1.4.1 Bondply to otherwise untreated polyimide.

2 Facing adhesives from coverlay and bondply.

3 Bondply to untreated copper.

4 Bondply to etched circuitry.

5 Bondply to the adhesive surface left after normal etching, stripping, and baking of flexible printed wiring two layer "details".

6 Treated copper to treated polyimide (the vendor's clad lamination).

7 Coverlay to otherwise untreated polyimide.

8 Coverlay to untreated copper.

9 Coverlay to etched circuitry.

10) Coverlay to the adhesive surface left after normal etch, strip and bake of double clad flexible printed wiring "details".

11) Treated copper to treated polyimide (as a confirmation of paragraph 6, except from the other side of the vendor's clad lamination).

6.3.1.5 Remaining Peel Tests

This still does not include the Method C narrow etched strips, wide strips on the original vendor clad laminate as received, or adhesion to epoxyglass. However, there is no need for any preparation for the wide strips of original vendor clad laminate, and extra etched strips can be prepared as part of the print and etch procedure preceding the above multiple layer lamination. Additional information is available by testing peel strengths on these samples both before stripping of resist, after stripping, and after baking one hour at 250°F. Epoxyglass adhesion is more relevant to flex-rigid hybrid fabrication, and can be a separate sample to avoid excessive thickness and rigidity of the above peel test samples.

6.3.2 Peel Tests to Copper Clad Laminates

For Method A, wide strips of the vendor's double clad materials, as received, gave the following peel test averages:

Acrylic ------------ 12.6

Phenolic Butyral --- 8.3

6.3.3 Peel Tests to Copper Clad Laminates After Etching Copper

For Method C, narrow strips of copper are formed for peeling by normal print and etch methods. Some were peeled directly, others after immersions for controlled times in one of a variety of specified solvents or molten solder. In these critical peel tests for copper bond strength, as received and after various chemical and thermal exposures, the differences among materials is really significant. Of the three adhesive types (acrylic, phenolic butyral, and modified epoxy), only the acrylic passed the "as received" tests. The phenolic butyral also had individual test failures after MEK and after 2N HCl, and general failures after solder immersion. The high temperature exposure test proved too severe, with all the tested materials failing, so those tests were repeated under less severe overstress conditions, with unetched clad material.

6.3.3.1 As Etched

Values shown are averages which include the undipped portions of "after solvent immersion" tests.

Acrylic ----------- 7.7
Phenolic Butyral --- 5.1
Modified Epoxy ---- 5.5

6.3.3.2 After Solder Immersion

Since the solvent immersions did not appear significantly deleterious, the solder immersion (which certainly influences actual usage, due to solder bonding of connectors and parts in production flexible printed wiring assemblies) are listed next.

Acrylic ------------6.5
Phenolic Butyral----4.1
Modified Epoxy ----6.7

Note that in a few instances where high temperatures are involved, the modified epoxy shows results comparable to the acrylic, but results overall were less favorable for the modified epoxy.

6.3.3.3 After Solvent Immersions

Samples were immersed for specified times in each of the organic solvents, mixtures, and aqueous chemical solutions (acid and base) listed, but note that each sample was immersed in only one "solvent" prior to test. Results were:

TABLE V: Peel Strength on Etched Clad Laminate After Solvent Exposure

Solvent	Adhesive System		
	Acrylic	Phenolic Butyral	Modified Epoxy
Isopropyl Alcohol	7.5	5.4	6.4
Toluene	8.7	4.9	6.0
MEK	13.7	4.6	6.1
50-50 Chlorinated	12.4	5.0	5.8
2 N HCl	7.5	3.7	8.6
2 N NAOH	7.7	4.9	8.7
Averages:	9.6	4.8	6.9

6.3.3.4 After High Temperature Exposure for 24 Hours

As mentioned earlier, all materials failed this test grossly, so comparison of results is not relevant.

6.3.4 Peel Tests to Adhesive Coated Insulation Sheets

These are Method A peel tests on one inch wide strips, with comparable tests on both coverlay and bondply. These tests were performed on laminations prepared per the varying vendor's recommendations, onto three different surfaces: 1) bare copper (after acid dip, rinse, dry and 250°F bake for one hour), 2) epoxy glass, prepared by etching copper from clad circuit board material, rinse, dry and 250°F bake for one hour), and 3) "untreated" bare polyimide. The polyimide side of outdated (scrap) coverlay was used for the "untreated polyimide". It received no special treatment, not even baking, before either the acrylic or the phenolic butyral lamination, just like the coverlay and bondply, in tests of those materials. Under these conditions of bonding to bare polyimide, which is not required in any of our flexible printed wiring designs, peel strength is very poor. Although the peel strengths to unbaked, untreated polyimide are all too low to be useful, the acrylic results are still not as bad as those for phenolic butyral. Both were treated identically in these tests, though treated differently in the film adhesive tests which follow in paragraph 6.3.5. The thickness of the polyimide in the coverlays which were used for the early tests was 2 mils with phenolic butyral, but only one mil with the acrylic and modified epoxy adhesives. These thicknesses were therefore continued throughout as shown in the Test and Evaluation Plan. There were more polyimide failures with the thinner coverlay materials. Whenever less than 40% of the tests gave values, the group was left out. From the remaining successful tests, the following averages of peel strengths were obtained:

6.3.4.1 As Laminated:

TABLE VI: Peel Strength of Adhesive Coated Insulation Sheets As Laminated

	Surface to Which Bonded						Avg.
	Bare Copper		Epoxyglass		Untreated Polyimide		
Adhesive Material: Kind of Adhesive:	Bondply	Coverlay	Bondply	Coverlay	Bondply	Coverlay	
Acrylic	7.0	-	7.7	-	2.5	-	5.7
Phenolic Butyral	8.3	-	6.3	5.1	1.5	1.1	4.4
Modified Epoxy	-	-	-	4.3	-	-	4.3
Averages	7.7	-	7.0	4.7	2.0	1.1	-

This table by itself is not too conclusive, and the results for bondply bonded to bare copper using phenolic butyral are especially high, compared with the routine qualification test results during the past year,

which have generally had frequent difficulties in passing the 3.0 lbs/inch acceptance requirement. However, the acrylic overall averages still show some superiority, which is sufficiently bolstered by those of other peel test material categories herein to be decisive. In future work, tests could also be performed at the specific process parameters used for Production, rather than simply per the vendor's recommendations, for more realistic information on expected product quality or any variations therein.

6.3.4.2 After Solder Immersion

TABLE VII: Peel Strength of Adhesive Coated Insulation Sheets After Solder Immersion

	Surface to Which Bonded						Avg.
	Bare Copper		Epoxyglass		Untreated Polyimide		
Adhesive Material:	Bondply	Coverlay	Bondply	Coverlay	Bondply	Coverlay	
Kind of Adhesive:							
Acrylic	6.7	-	9.0	-	1.3	-	5.7
Phenolic Butyral	4.4	-	5.8	-	0.8	0.7	2.9
Modified Epoxy	-	3.5	-	3.3	-	-	3.4
Averages	5.6	3.5	7.4	3.3	1.1	0.7	-

Remember that "untreated polyimide" here does not represent a production condition. Acrylic obviously shows the best results in this data for peel strength after solder immersion.

6.3.4.3 After Solvent Exposure

TABLE VIII: Peel Strength of Adhesive Coated Insulation Sheets After Solvent Exposure

	Surface to Which Bonded						Avg.
	Bare Copper		Epoxyglass		Untreated Polyimide		
Adhesive Material:	Bondply	Coverlay	Bondply	Coverlay	Bondply	Coverlay	
Kind of Adhesive:							
Acrylic	7.3	5.0	9.2	-	3.6	-	6.3
Phenolic Butyral	7.6	5.5	7.0	5.4	1.6	1.2	4.7
Modified Epoxy	-	-	-	3.2	-	-	3.2
Averages	7.5	5.3	8.1	4.3	2.6	1.2	-

Comparison with the "as laminated" data reveals no significant damage from these solvent exposures. In fact, the overall averages are slightly higher after solvent exposure.

6.3.5 Peel Tests to Adhesive Film

These are likewise Method A peel tests on inch wide strips, with one mil thick cast adhesive of both acrylic and phenolic butyral for comparison. The phenolic butyral tests were laminated on the same day with the coverlay and bondply per paragraph 6.3.4, while the supply of acrylic cast adhesive was exhausted. Note that the untreated polyimide was not baked for these first laminations. Some improvement was essential to yield meaningful results since: 1) the Test and Evaluation Plan (Reference 7) specified that untreated polyimide be used on one side of all these laminations, 2) adhesion to untreated polyimide is notoriously poor, and 3) the acrylic vendor had already recommended baking of "all materials" before lamination. Therefore, the "untreated polyimide" was baked for one hour at 250°F before the later lamination with acrylic adhesive film. This proved quite successful in improving the adhesion of acrylic to polyimide, but prevents any meaningful comparison of peel strengths of film adhesives between two sheets of untreated polyimide. In fact, since the peel interface of a relatively low tensile strength adhesive material will generally tend to peel at the weakest interface, even the tests of adhesive films against copper and epoxy glass are suspect, since polyimide was bonded to the other side.

6.3.5.1 As Laminated (For Film Adhesive)

TABLE IX: Peel Strength of Film Adhesive As Laminated

Polyimide to: / Kind of Adhesive:	Bare Copper	Epoxyglass	Untreated Polyimide	Avg.
Acrylic (with polyimide baked)	6.6	6.2	5.8	6.2
Phenolic Butyral (without polyimide bake)	4.1	2.2	1.2	2.5
Averages	5.4	4.2	3.5	

The effect of baking the untreated polyimide before lamination on peel strengths is obvious from comparing Table VII to Table IX. The relatively high peel strengths of the acrylic film adhesive to the epoxyglass and baked polyimide materials found in flex rigid hybrids also indicate that further cost savings are probably available in adapting acrylic adhesive materials promptly to the more difficult flex-rigid hybrid fabrications.

6.3.5.2 After Solder Immersion (For Film Adhesive)

TABLE X: Peel Strength of Film Adhesive After Solder Immersion

Polyimide to:	Bare Copper	Epoxyglass	Untreated Polyimide	Avg
Kind of Adhesive:				
Acrylic (to baked polyimide)	5.4	6.1	6.8	6.1
Phenolic Butyral (to unbaked polyimide)	2.4	-	0.4	1.4
Averages	3.9	-	3.6	

Acrylic shows a major advantage in that there is much lower percentage degradation of adhesion after solder immersion, but the data are not otherwise comparable because of the difference in baking polyimide.

6.3.5.3 After Solvent Immersion (For Film Adhesive)

TABLE XI: Peel Strength of Film Adhesive After Solvent Exposure

Polyimide to:	Bare Copper	Epoxyglass	Untreated Polyimide	Avg
Kind of Adhesive:				
Acrylic (to baked polyimide)	5.8	6.2	5.6	5.9
Phenolic Butyral (to unbaked polyimide)	4.0	1.6	1.1	2.2
Averages:	4.9	3.9	3.4	

Comparison with par. 6.3.5.1 does not show any statistically significant reduction of peel strength after solvent immersion beyond the 20% presently allowed in the IPC material tests.

6.3.6 Peel Strength Tests on Two Layer FPW

6.3.6.1 Specification References: Method C of IPC-TM 650-2.4.9 except using test pattern "C" of GDP drawing SP 133-5040. GDP TM-6-133-164, paragraph 13. GDP MPS 90.69E.

6.3.6.2 Test Equipment: As specified in IPC-TM 650-2.4.9, paragraph 4.0.

6.3.6.3 Applicability: This section 6.3.6 is limited to two layer FPW, which in this program were fabricated only with the acrylic adhesive system.

6.3.6.4 Sample Size

Five samples of test pattern "C" that have been fabricated in accordance with paragraph 8.1.3 herein, were used for the following peel strength tests.

6.3.6.5 Sample Preparation

Care was taken to remove the specified test patterns from the laminated assemblies without causing damage to the surrounding test patterns. If any delamination had occurred during the cut-out process, the edges would have been repaired in accordance with MPS-90.69E, and the repair would have been noted on the corresponding data sheet, but none occurred.

6.3.6.6 Method ("C") with Exceptions)

A total of nine peel strength tests were performed on each of the five test patterns in accordance with IPC-TM 650-2.4.9, paragraph 5.3 (Method C), except paragraphs 5.3.1 and 5.3.2 are not applicable. The peel strength tests were performed in two separate groups for each test pattern. The .020 wide paths were tested as one group, and the required force, force conversion and group average were recorded as specified on the applicable data sheet. The 0.100 paths were also tested as a separate group, and the required force, force conversion and group average were recorded as specified on the applicable data sheet.

6.3.6.7 Requirements

6.3.6.7.1 The peel strength was reported in pounds per inch of width as a minimum average of the two test groups on each of the five test patterns.

6.3.6.7.2 The peel strength of the etched and plated conductors to the base dielectric must be a minimum of 7 pounds per inch of effective conductor width at point of contact.

6.3.6.7.3 Record all data in accordance with the requirements specified on the applicable data sheet.

6.3.6.8 Results: These tests were done only on acrylic two layer FPW, yielding averages of 13.6 for .020 inch width and 16.6 for 0.100 inch widths. The lower value of the narrower line is presumably due to edge effects.

6.3.6.9 Conclusions

These values are excellent for peel strength tests by Method "C", and are even well above those for the original clad laminate after etching. It is possible that the modifications of lamination parameters developed for this program may have had some influence in the improvement of acrylic FPW peel strength results over the earlier material tests on laminations made per specification "at the vendor's recommended conditions". This increase was from 8 lbs/inch (on the etched, treated-copper-clad, polyimide-acrylic laminates tested by Method C) to an average of 15 lbs/inch width on the two layer FPW. However, part of this increase in peel strength may have resulted from the partial encapsulation of the etched copper circuitry by the acrylic adhesive during the coverlay lamination operation. Since this is an integral part of most FPW fabrication, the real goal for FPW in achieving high peel strengths is at this post-coverlay or final product stage. The materials results, however, provide more economical comparative test studies by avoiding extra FPW fabrication costs.

6.3.7 Peel Strength Tests on Multilayer FPW Test Pattern

6.3.7.1 Specification References

IPC-TM 650-2.4.9, except using test pattern "C" of GDP drawing SP133-5047. GDP TM 6-133-168, paragraph 13. GDP MPS-90.69E.

6.3.7.2 Test Equipment

As specified in IPC-TM 650-2.4.9, paragraph 4.0.

6.3.7.3 Applicability

This section 6.3.7 is limited to multilayer FPW, which are four layer FPW fabricated only with acrylic materials in this program.

6.3.7.4 Sample Size

Five samples of test pattern "C" that were fabricated in accordance with paragraph 8.1.3 herein were used for the following peel strength tests.

6.3.7.5 Sample Preparation

Care was taken to remove the specified test patterns from the laminated assemblies without causing damage to the surrounding test patterns. If any delamination had occurred during the cut-out process, the edges would have been repaired in accordance with MPS-90.69E, and the repairs would have been noted on the corresponding data sheet, but no delamination occurred.

6.3.7.6 Method ("C" With Exceptions)

A total of nine peel strength tests were performed on each of the five test patterns in accordance with IPC-TM 650-2.4.9, paragraph 5.3 (Method C), except paragraphs 5.3.1 and 5.3.2 are not applicable. The peel strength tests were performed in two separate groups for each test pattern. The .020 inch wide paths were tested as one group, and the required force, force conversion and group average were recorded as specified on the applicable data sheet. The 0.100 inch wide paths were also tested as a separate group, and the required force, force conversion and group average were recorded as specified on the applicable data sheet.

6.3.7.7 Requirements

6.3.7.7.1 The peel strengths were reported in pounds per inch of width as a minimum average of the two test groups on each of the five test patterns.

6.3.7.7.2 The peel strengths of the etched and plated conductors to the base dielectric were a minimum of 7 pounds per inch of effective conductor width at point of contact.

6.3.7.7.3 All data was recorded in accordance with the requirements specified on the applicable data sheet.

6.3.7.8 Results

These tests were done only on acrylic four layer FPW, yielding averages of 12.9 for .020 inch width and 8.7 for 0.100 inch widths. The lower value of the wider lines is contrary to previous results herein, but still well above the specified requirement.

6.3.7.9 Conclusions and Recommendations

The clad copper of the multilayer parts had undergone two each of the baking operations and laminations (one with bondply, and one with coverlay). It is conceivable that the multiple heat cycles might even cure the parts past their optimum cure, so that the solvent effects on the etch edges may be beneficial to peel strength by increasing flexibility. This is only conjecture, but suggests an area deserving further study when conditions (schedule and funding) permit. These acrylic multilayer peel strengths are very good and should improve FPW yield and reliability.

6.3.8 <u>Peel Strength Tests on Multilayer Pilot Lot FPW</u>

6.3.8.1 Specification References

MIL-P-50884B, paragraphs 3.13 and 4.7.9.GDP TM 6-133-174, paragraph 14.

6.3.8.2 Test Equipment

As specified in MIL-P-50884, paragraph 4.7.9.

6.3.8.3 Applicability·

This Section 6.3.8 is limited to the pilot lot of multilayer FPW, which in this program were fabricated only with the acrylic adhesive system.

6.3.8.4 Sample Size

Two samples identified as SP 133-5067C-3 and SP133-5067C-4 were subjected to the following peel strength tests.

6.3.8.5 Sample Preparation

There was no special sample preparation required for this test.

6.3.8.6 Method

6.3.8.6.1 The peel strength tests were conducted on the two specified test samples in the following manner. Each test pattern consisted of five .020 wide paths and four 0.100 wide paths. The two path widths were divided into two separate test groups for each of the two test patterns. The peel strength test were performed on each group of the same path width, and the force readings on each path were converted to lbs. of force/inch of width, then the average taken for each test group. The average results from each test group were compared to the actual requirement.

6.3.8.6.2 The peel strength test was performed on the four test groups (two test groups on each of two test samples) as specified in MIL-P-50884B, para 4.7.9.

6.3.8.7 Requirements

6.3.8.7.1 The average peel strength of the etched conductor for each test group shall be a minimum of 7 lbs. per inch of effective conductor width at point contact.

6.3.8.7.2 Record all data in accordance with the requirements specified on the applicable data sheet.

6.3.8.8 Results

These tests were done only on acrylic multilayer pilot lot FPW, yielding averages of 13.3 for .020 inch widths and 12.8 for 0.100 inch widths. These values did not significantly vary with width.

6.3.8.9 Conclusions and Recommendations

Both widths gave excellent peel strength values, which should lead to improved FPW yield and reliability, and a strong recommendation for change from the two-adhesive phenolic butyral system to the single adhesive acrylic system for FPW fabrication.

6.3.9 <u>Summary of Peel Strength Test Results</u>

6.3.9.1 For this project, the mass of peel strength data obtained was sufficient to show the superiority of the acrylic in the averages, even though the variation between tests, and the loss of dependable results on some tests by polyimide failures, makes it inadvisable to place too much credence on individual tests results. Obviously none of the solvents or the solder immersion created significant adverse effects beyond the 20% decrease in strengths allowed in the IPC specifications.

The preliminary test data is as expected except for the laminations to untreated insulation sheet. These values fall below the established seven (7) pounds per inch width. It also appears that the high temperature exposure test will not produce any usable data for this evaluation as a 24 hour exposure to 400°F degraded all of the adhesive systems being evaluated to the charring point, making all ineffective for flexible printed wiring.

This facet deserves further investigation in future projects, but is not critical in selecting from among the different adhesives for current flexible printed wiring fabrication needs, and such further investigation was beyond the scope of this project.

6.3.9.2 The acrylic adhesive shows significant advantages in the peel strength results among the three adhesive types tested, not only on the as-received clad laminates, but also on the laminations to untreated copper, epoxyglass, and untreated polyimide, and on the peel tests after the various immersion treatments. As expected, none of the adhesive materials tested consistently pass all of the very stringent goals which were set as estimated upper limits in the evaluation plan. In some cases, quantitative values were not obtained because of polyimide failures. Peel strengths as determined on the narrow etched strips by "Method C" frequently yielded lower values than on the wider strips of "Method A", due to the addition of "edge effects". The average peel strength also varied considerably, as expected, according to whether the adhesive was laminated to the treated copper of vendor-supplied laminates, untreated copper, untreated polyimide, or bare epoxyglass.

6.3.9.3 This study has shown the following:

1) Only the acrylic adhesive passed the original goal of 7 lbs. per linear inch for Method C tests of as-received copper clad laminates. 2) The peel strength values after an immersion (in one of the various solvents, acid, base or molten solder) sometimes show more reduction than the 20% allowed in the original plan, in terms of percentage of the peel strengths on the untreated portions. Surprisingly enough, the peel strengths also show major increases (sometimes exceeding 50%) after some immersions. None of the "after immersion" peel test averages indicated as much damage to the acrylic adhesives as some of those tests indicated on the other two adhesive systems. 3) When laminated to untreated copper, the acrylic adhesive provided the highest average peel strengths. The lowest average peel strengths for lamination to untreated copper by Method A (as laminated, and after any immersion category) was 4.3 for acrylic versus 2.4 and 1.4 for the other two adhesive systems. 4) Although the acrylic adhesive film was the only material, among those tested, which provided acceptable peel strength values on untreated polyimide laminations, this is not a fair comparison, since it, by chance, became the only material laminated to pre-baked polyimide. 5) The 24 hour baking in air at 400°F. proved too extreme for any of these laminates. Based on these results, more realistic conditions will be used in near-future specifications. 6) The epoxyglass laminates likewise indicated that the acrylic peel strengths were best.

6.3.9.4 Peel Test Result Averages

The peel test results were averaged and examined in several different categories. They were averaged for multiple peel tests per sample type, for type of adhesive (acrylic, phenolic butyral, or modified epoxy), for material type (copper laminate, coverlay, bondply, or film adhesive), for material to which bonded (copper, epoxyglass, or polyimide) and for "as laminated" versus "after exposure". These averages of all the available peel strength data may be summarized as follows, remembering that good adhesion to untreated polyimide is not required in current General Dynamics designs.

TABLE XII: Overall Averages of Peel Strength Data

	ACRYLIC		PHENOLIC BUTYRAL		MOD. EPOXY	
	As Laminated	After Exposure	As Laminated	After Exposure	As Laminated	After Exposure
Treated Copper As:						
Narrow Etched Strips	7.7	10.6	5.1	4.7	5.5	6.9
One Inch Wide Strips	12.6	--	8.3	--	--	--
Film, Coverlay & Bondply to:						
Bare Copper	6.1	5.9	6.2	5.5	--	2.2
Epoxyglass	7.0	7.7	4.5	4.6	4.3	3.2
Untreated Polyimide	3.0	3.2	1.3	1.2	2.2	2.4
Overall Average:	7.1		4.6		3.8	

The peel strength data is averaged again below to eliminate the data from and effect of all those tests which used unbaked, untreated polyimide and all which used film adhesive. The latter involved a difference between the original unbaked polyimide used with phenolic butyral film adhesive and the improved process with baked polyimide used with acrylic film adhesive.

6.3.9.4 Peel Test Result Averages (Cont'd)

TABLE XIII: Peel Strength Averages Excluding Unbaked Polyimide and Film Adhesive Tests

Adhesive Type:	ACRYLIC		PHENOLIC BUTYRAL		MOD. EPOXY	
	As Laminated	After Exposure	As Laminated	After Exposure	As Laminated	After Exposure
Treated Copper:						
Narrow Etched Strips	7.7	10.6	5.1	4.7	5.5	6.9
One Inch Wide Strips	12.6	-	8.3	-	-	-
Coverlay & Bondply to:						
Bare Copper	5.9	6.0	8.3	6.4	-	2.2
Epoxyglass	7.7	9.2	5.7	6.1	4.3	3.2
Overall Average:	8.5	8.6	6.9	5.7	4.9	4.1

Note that this still shows the same relative positions and conclusions as the preceding table, though all values are increased by eliminating the lower values.

6.3.9.5 TABLE XIV: Peel Strengths Before and After Solder Immersion

	ACRYLIC	PHENOLIC BUTYRAL
As Laminated: (Avg. of over 150 Peels for Each)	6.1	4.3
After Solder Immersion: (Avg. of over 20 peels)	5.8	2.7

6.4 OTHER MECHANICAL STRENGTH-RELATED TESTS:

Basically, polyimide is known to be strong but easily ripped. The annealed copper used in the clad materials has good elongation, and the problem is generally to provide copper electroplating with at least fairly good elongation. The adhesives generally add little to strength but should not become too brittle after necessary heat and time exposure of assembly and typical storage conditions.

6.4.1 Tensile Strength

6.4.1.1 Specification References: IPC-TM650-2.4.19 and 2.4.18.

6.4.1.2 Test Equipment: As specified in IPC-TM 650-2.4.19.

6.4.1.3 Applicability: The copper clad laminate (after removing copper by etching) and the adhesive coated insulation sheet were tested for tensile strength. Film adhesive was not tested because it contributes very low tensile strengths relative to the polyimide. Nor were any tensile tests performed, though obviously possible, on the two layer, four layer, or pilot lot FPW or on the unetched copper-clad laminates.

6.4.1.4 Sample Size

Five samples of each material tested were subjected to the following tensile strength test.

6.4.1.5 Sample Preparation: All copper clad materials subjected to this test were etched in accordance with paragraph 8.1.1 prior to start of testing. All test samples were prepared in accordance with IPC-TM 650-2.4.18, paragraph 5.1.1 prior to testing.

6.4.1.5.1 Samples were formed in accordance with Figure 1 of IPC-TM 650 - 2.4.18 after etching and prior to testing.

6.4.1.6 Method: The test procedure for all samples was in accordance with IPC 2.4.18, paragraph 5.1.

6.4.1.7 Requirements

6.4.1.7.1 The tensile strength shall be 20,000 psi minimum.

6.4.1.7.2 Record all data in accordance with the requirements specified on the applicable data sheet.

6.4.1.8 Results

6.4.1.8.1 After Etching Copper from Clad Polyimide: The proposed requirement of 20,000 psi was easily passed by all three polyimide materials, with averages of: Acrylic, 33,400; phenolic butyral, 31,500; modified epoxy, 32,300 psi, showing no significant differences.

6.4.1.8.2 Adhesive Coated Insulation Sheet: These showed greater variation in tensile strength than the clad materials above, but all passed 20,000 psi easily. Values were: Acrylic, 34,100; phenolic butyral, 27,000; modified epoxy, 27,900.

6.4.1.9 Conclusions on Tensile Strength

While tensile strength is a reasonable specification requirement to guarantee continuing conformance with present polyimide quality standards, it is not an important factor in selecting from among these three vendor's product lines of currently available FPW materials.

6.4.2 <u>Tear Strength (Initial)</u>

6.4.2.1 Specification Reference: IPC-TM 650-2.4.16 and GDP TM 6-133-128.

6.4.2.2 Test Equipment: As specified in reference above.

6.4.2.3 Applicability: Copper clad laminate (after removing copper by etching), and the adhesive coated insulation sheet were tested for initial tear strength.

6.4.2.4 Sample Size: Five samples of each material tested were subjected to the following initial tear strength test. All test samples were four inches square prior to etching.

6.4.2.5 Sample Preparation: All copper clad samples being subjected to this test were etched in accordance with paragraph 8.1.1 prior to start of testing. All test samples were prepared in accordance with IPC-TM 650 - 2.4.16, paragraph 5.1 prior to the start of testing.

6.4.2.6 Method: The test procedure for all samples was in accordance with IPC-TM 650 - 2.4.18, using paragraph 5.2.

6.4.2.7 Requirements

6.4.2.7.1 The minimum initial tear strength shall be 400 pounds/inch of total thickness (including adhesive).

6.4.2.7.2 Record all data in accordance with the requirements specified in the applicable data sheet.

6.4.2.8 Results on Initial Tear Strength

6.4.2.8.1 After Etching Copper from Clad Polyimide

The averages of five samples were:

Acrylic.................	513 lbs/inch thickness
Phenolic Butyral........	340
Modified Epoxy	397

6.4.2.8.2 Adhesive Coated Insulation Sheet

The averages of four to five samples were:

Acrylic Bondply (1 mil polyimide) .... 511 lbs/inch thickness

Acrylic Coverlay (1 mil polyimide)............ 526

Phenolic Butyral Bondply (1 mil polyimide)..... 644

6.4.2.8.3 Averages of all Tests from Each Adhesive System

Acrylic = (513 + 511 + 526) ÷ 3 = 517

Phenolic Butyral (340 + 644) ÷ 2 = 492

6.4.2.9 Conclusions on Initial Tear Strength

Among the clad materials, only acrylic passed the requirement of 400 lbs/inch of total thickness, although all tested adhesive coated insulation sheets passed. While there seems to be considerable variation among results, with higher values for acrylic clad material from which copper has been removed by etching, and higher values for phenolic butyral on adhesive coated insulation sheet, the averages by adhesive type are very close compared to the test variations. Considering some variations in material thickness, the differences in initial tear strength have not yet been proven large enough to be a major factor in selecting among these materials. Initial tear strength, like tensile strength, is still an important material specification requirement to protect against any future material or vendor deviations.

6.4.3 <u>Tear Strength, Propagate</u>

The original desire was to include a test of tear strength propagation, but the IPC test is designed for rigid printed circuit boards rather than for flexible printed wiring, and was not directly applicable. The polyimide materials are known to be tear-sensitive with notch effects, but such a test, even if available, would have little effect on this selection of an optimum adhesive material, at least under present conditions. All the materials tested use the same source of polyimide, and the adhesive portions contribute little to the total strength of the organics or dielectric materials in present flexible printed wiring, so the results would doubtlessly be comparable and inconclusive anyway. Therefore no "tear strength, propagate" tests were performed. The references hereto in these reports were just left in for "historical" purposes to avoid confusion regarding what happened to them.

6.4.4 Copper Foil Elongation

6.4.4.1 Specification References: IPC-TM 650-2.4.18 and 2.4.19.

6.4.4.2 Test Equipment

In accordance with IPC-TM 650 - 2.4.19, paragraph 4.

6.4.4.3 Applicability

Only the copper clad laminate was tested for copper foil elongation in this program. From an ultimate product standpoint, elongation is also a significant test for the electroplated copper (or a combination of clad plus electroplated copper), but it is of no importance to a selection among materials, which is the purpose of this program.

6.4.4.4 Sample Size

Five samples of each test material were subjected to the following copper foil elongation test.

6.4.4.5 Sample Preparation

All test samples were prepared in accordance with IPC-TM 650-2.4.18, Figure 1, paragraph 5.2.1 prior to testing.

6.4.4.6 Method

The test procedure for all samples was in accordance with IPC-TM 650-2.4.18, paragraph 5.2.2.

6.4.4.7 Requirement

6.4.4.7.1 The copper foil elongation

6.4.4.7.2 Record all data in accordance with the requirements specified on the applicable data sheet.

6.4.4.8 Results on Copper Foil Elongation

Three samples from each of the three clad laminates representing the three different adhesive systems (and vendors) were pulled to destruction, with all materials passing, and results averaging:

6.4.4.8 (Cont'd) Acrylic 14.6% Elongation

Phenolic butyral was 16.9% on 2 oz. copper, but when rerun with 1 oz. copper, gave 12.3%

Modified Epoxy 14.2%

6.4.4.9 Conclusion on Copper Foil Elongation

This is an important material qualification test for flexible printed wiring materials (because of their flexibility requirement) which is relatively insignificant for rigid printed wiring board materials. This requirement would disqualify most of the "electroplated copper" clad laminates currently available, though all three vendors in this test program used the "rolled, annealed" copper presently common to achieve high elongation values. Therefore these tests herein are not significant for selection among these three vendors, though results of this test might disqualify some future material applicants, and this test is therefore important for flexible printed wiring materials specifications. The increase in elongation shown by the thicker copper of the phenolic butyral copper clad material elongation tests is the natural result of the reduced fraction of total thickness which is affected by the copper oxide surface treatment which precedes vendor laminations.

6.4.5 Flexural Fatigue

6.4.5.1 Specification References: IPC-TM 650-2.4.3

Use Method A for materials. Use Methods A and B, except using test patterns G and H from drawing SP 133-5040 for two layer FPW, and from drawing SP 133-5047 for four layer FPW. GENERAL DYNAMICS, Pomona (GDP) MPS T120.26H for etching and MPS 90.69 if repair is needed.

6.4.5.2 Test Equipment: GDP SP 133-5054.

6.4.5.3 Applicability

The copper clad laminate, the two layer FPW, and the four layer FPW were tested for flexural fatigue. The number of cycles before failure in this test varies greatly according to thickness of the FPW, layer location of the tested copper pattern, plating thickness, and copper elongation. Therefore wide variations in requirements were established according to test pattern, location, coverlay, and number of layers.

6.4.5.4 Sample Size

Five samples of each test material and/or test pattern were tested, each of such a size (after etching and trimming) to accommodate testing using test equipment SP 133-5054.

6.4.5.5 Sample Preparation

6.4.5.5.1 Five test panels of each tested material category and FPW pattern were fabricated as described herein under Fabrication (Section 8) for the corresponding test parts, using test patterns G and H, which are included on drawing SP 133-5040, for materials and two layer FPW, and on drawing SP 133-5047 for multilayer FPW.

6.4.5.5.2 Note that the FPW test parts are also electroplated one mil thick minimum with copper, which has a major effect upon Flexural Fatigue test results.

6.4.5.5.3 *Trim Delamination*

If delamination occurred during the cut-out process on FPW test parts, the edges were repaired in accordance with GDP MPS 90.69E, and the event recorded under remarks on the corresponding data sheet.

6.4.5.6 Method

All five samples of each tested material or FPW category were tested in accordance with IPC-TM 650-2.4.3, except that test equipment SP 133-5054 was used.

6.4.5.6.1 Method A

Paragraph 5.1 (Method A) of IPC-TM 650-2.4.3 was used with test pattern H (which has no covercoat) for flexural fatigue tests on both clad materials and FPW tests.

6.4.5.6.2 Method B

Paragraph 5.2 (Method B) of IPC-TM-650-2.4.3 was used with test pattern G (which does have a covercoat) for FPW test only.

6.4.5.7 Requirements

6.4.5.7.1 The unplated, double clad copper laminate material, as received from vendor, shall withstand 2,500 cycles minimum of the flexural fatigue test without loss of electrical continuity. The flexible printed wiring test pattern H, without covercoat, shall withstand 1,250 cycles minimum on two layer FPW and 2,500 cycles minimum on four layer FPW, while the covercoated test pattern G shall withstand 1,250 cycles minimum on two layer FPW and 125 cycles minimum on four layer FPW.

6.4.5.7.2 Record all data in accordance with the requirements specified on the applicable data sheet.

6.4.5.8 Results on Flexural Fatigue

Note all tests were stopped at 20,000 cycles for clad material and 10,000 cycles for FPW, and averages include those maximum values when achieved.

6.4.5.8.1 Double clad material, including 1 ounce rolled, annealed copper:

ADHESIVE SYSTEM	AVERAGE	MINIMUM	MAXIMUM
Acrylic	11,848	6,508	>20,000
Phenolic Butyral	9,247	4,535	12,302
Modified Epoxy	19,327	17,310	>20,000

The modified epoxy results exceeded those of acrylic, which in turn was ahead of the phenolic butyral.

6.4.5.8.2 Two layer FPW (Four samples each of acrylic only)

6.4.5.8.2.1 Pattern H (without covercoat) survived an average of 1,920 cycles with a minimum of 1,392 cycles.

6.4.5.8.2.2 Pattern G (with covercoat) survived an average of 3,696 cycles with a minimum of 1,990 cycles.

6.4.5.8.3 Four Layer FPW (Five samples each of acrylic only)

6.4.5.8.3.1 Pattern H (without covercoat) includes only the two unplated internal layers of the multilayer test pattern, so these results are more comparable to "clad material", except that the etched lines are encased in the adhesive and protected by the polyimide from the outer layers by the multilayer lamination. None of the five samples failed during 10,000 cycles.

6.4.5.8.3.2 Pattern G (with covercoat) includes lines on all four layers of this multilayer FPW, of which the outer two layers are not only electroplated (with lower copper elongation values) but are also subjected to greater compression and elongation in bends due to the increased thickness, or distance from the centerline in the "Z" axis (perpendicular to the part plane) in a bend. These averaged only 222 cycles, with a minimum of 126 cycles completed at failure. All failures, as expected, were on the plated lines on the external layers.

6.4.5.9 Conclusions on Flexural Fatigue

This test itself is obviously not infallible, since results are affected by the non-uniformity of the bending radius over the test length, and therefore show considerable deviation within each material's results. However, it is an improvement over some previous tests and is still valuable until something better becomes available. The modified epoxy performed exceptionally in this test, and acrylic results look good. It seems reasonable to suspect that lower peel strength could be one of the factors reducing the values for phenolic butyral, though that is obviously not a factor with the acrylic. Results were likewise very good on the internal, unplated layers of the acrylic multilayer FPW. The reduction of flexural fatigue cycles was to be expected on plated two layer FPW, and on the external plated layers of the multilayer FPW. These tests do provide an opportunity for measuring future progress on copper electroplating improvements, and provide insight into potential design improvements and design ground rules when and if future design requirements undergo major increases in flexibility needs.

6.4.6 Folding Endurance

6.4.6.1 Specification References

IPC-TM 650-2.4.5, except requiring no electrical tests for the clad laminate, and except using test pattern "A" (from drawing SP133-5040 for two layer FPW, and from drawing SP 133-5047 for multilayer FPW) after its prior use for the tests of paragraphs 6.7.3 (dielectric withstanding voltage) and 6.5.3 (solderability).

6.4.6.2 Test Equipment

Test apparatus specified in IPC TM 650-2.4.5, paragraph 4.0 was used, except no electrical test equipment is required for the clad laminate.

6.4.6.3 Applicability

The copper clad laminate (as received) plus the two layer and multilayer FPW test patterns were tested for folding endurance. The folding endurance of the dielectric and adhesive materials is too high to provide a practical comparison in this test.

6.4.6.4 Sample Size

Five samples of each tested material were subjected to the following folding endurance test. All five sample of each clad laminate test specimen were cut into 6 inch squares prior to testing.

6.4.6.5 Sample Preparation

No special sample preparation is required for clad laminate, which is tested as received. For all FPW, the "A" patterns described herein were tested for folding endurance after their prior use per paragraph 6.5.3.6 below.

6.4.6.6 Method

All tested samples were subjected to the folding endurance test described in IPC-TM 650-2.4.5. For clad laminates, paragraph 5.1 was used except that no electrical tests are required. For all FPW, paragraph 5.0 was used.

6.4.6.7 Requirements:

6.4.6.7.1 The copper clad laminate shall not exhibit separation or cracks after two cycles of folding. For all FPW test samples (pattern "A"), there is no specified requirement, but the samples shall be examined for separation and cracks after two complete cycles of folding.

6.4.6.7.2 Record all data or descriptive comments in accordance with the requirements specified on the applicable data sheet.

6.4.6.8 Results

AD-A045 354 GENERAL DYNAMICS/POMONA CALIF POMONA DIV F/G 11/9
PRODUCTION PROCESS DEVELOPMENT FOR POLYIMIDE-ACRYLIC MATERIALS --ETC(U)
SEP 77 S A HAYS, W A SMITH, F K SAWYER N00123-76-C-0138

UNCLASSIFIED M-24-S-476 NL

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A045 354

6.4.6.8.1 Copper clad laminate material

Failure rate was 20% on the acrylic samples, versus 40% on the phenolic butyral samples.

6.4.6.8.2 Two layer and multilayer FPW

Copper lifted from the polyimide on all five of the two layer and on two of the five multilayer FPW samples tested. The copper cracked on the other three multilayer FPW samples.

6.4.6.9 Conclusion on Folding Endurance

In retrospect, it is obvious that this test is too severe for both the double and multilayer FPW, so that it is really only applicable to the copper clad materials as received. Even for these, specification of some definite dimension mandrel for a larger bending radius, possibly in combination with a roller, should provide more quantitative comparisions among materials. Variations in thickness of either copper or dielectrics, and differences between single and double clad laminates, should also affect the results of this test. Though the acrylics had a lower failure rate than the phenolic butyral in this test, probably because of the difference in peel strengths of these adhesives to treated copper, this test probably was not in itself of major significance in the choice between materials.

6.4.7 <u>Terminal Area Bond Strength</u>

6.4.7.1 Specification References

IPC-TM 650-2.4.20, except using test pattern D (of drawing SP 133-5040 for two layer FPW, of drawing SP 133-5047 for four layer FPW, and of drawing SP 133-5067 for multilayer pilot lot FPW), and GDP TM's 6-133-164 (paragraph 12), -168 (paragraph 12), and -174 (paragraph 13).

6.4.7.2 Test Equipment

As specified in IPC-TM 650-2.4.20, paragraph 4.0.

6.4.7.3. Applicability

All test FPW (two layer, multilayer, and multilayer pilot lot) shall be tested for terminal area bond strength. Since it involves the plated through holes and etched pads, it is not practical to apply this test to raw materials. This tends to test a combination of thermal shock, peel strength, FPW etched pad and plated through hole strength, and

6.4.7.3 Applicability
(Cont'd)

resistance to delamination. This is a very practical test, since most electrical interconnections between the FPW and the outside world which uses it are presently through such terminal area bonds. Except for cracks or delaminations leading to opens or shorts from excessive bending, it seems probable that the next major source of FPW failures would be related to terminal area bond failures.

6.4.7.4 Sample Size

Test pattern "D" of five samples of 2 layer FPW, five samples of 4 layer FPW, and the two samples identified as E-3 and E-4 of pilot lot FPW (from drawings SP 133-5040 for two layer FPW, SP 133-5047 for four layer FPW or SP 133-5067 for multilayer pilot lot FPW), after fabrication in accordance with Section 8 herein, were subjected to the following terminal area bond strength test.

6.4.7.5 Sample Preparation

6.4.7.5.1 All samples were prepared in accordance with IPC-TM 650-2.4.20, paragraph 5.1, except that all eight holes on each test pattern of the two layer FPW and four layer FPW were used. On the multilayer pilot lot FPW, prior to testing, four terminal areas on each test sample identified as J 57-11, J 57-15, J3-15 or J1-31 were prepared in accordance with MIL-P-50884B, paragraph 4.7.8, then pre-dried at 71°C maximum for one hour.

6.4.7.5.2 Care was taken to remove the specified test patterns from the laminated assemblies without causing damage to the surrounding test patterns.

6.4.7.5.3 If delamination had occurred during the cut out process. the edges would have been repaired in accordance with GDP MPS 90.69E, and the repair would have been noted on the corresponding data sheet, except that pilot lot FPW would not be repaired. No delamination occurred.

6.4.7.6 Method

6.4.7.6.1 The solder cycles were performed in accordance with IPC-TM 650-2.4.20, paragraph 5.2, except for the multilayer pilot lot FPW. On all four terminals of each of the two pilot lot test samples described above, five complete cycles of soldering and unsoldering were performed as specified in MIL-P-50884B, paragraph 4.7.8.

6.4.7.6.2 The testing of all test samples was in accordance with IPC-TM 650-2.4.20, paragraph 5.3, except for the pilot lot FPW. The pull tests were performed on the pilot lot FPW as specified in MIL-P-50884B, paragraph 4.7.8.

6.4.7.7 Requirements

6.4.7.7.1 After five complete cycles of soldering and unsoldering, each terminal shall withstand a minimum of five pounds pull.

6.4.7.7.2 After the pull test, the plated holes shall not be loosened, and there shall be no evidence of conductor cracking, delamination, or wetting.

6.4.7.7.3 Record all data in accordance with the requirements specified on the applicable data sheet.

6.4.7.8 Results

These tests apply only to FPW, and only acrylic FPW were tested in this program plan. On the two layer FPW, there were only four failures out of 28 tested holes, and all four were close to passing, failing at pulls of between 4.4 and 4.8 pounds. On the four layer FPW, all 40 tested holes passed the five pound test. The pulling force was then increased until pullout for all 40 sample holes, and the pullout strength values ranged from 6.1 to 15.5, with 60% of them at 10 or above. The pilot lot was only tested to the five pound level, and the holes were then cross-sectioned and mounted to determine whether any defects not visible to the naked eye could be found by microscopic study of the cross sections. The acrylic pilot lot samples passed this test also, but two of four phenolic butyral multilayer plated though holes tested similarly on routine production samples did show cracking failures from the five pounds pull after the five solder cycles.

6.4.7.9 Conclusions

The extra physical strength of the multilayer FPW compared to the thinner two layer FPW appears to permit the higher terminal area bond strength of the multilayer FPW. The acrylic results were very favorable, and the phenolic butyral failures seem to correlate with the differences obtained in the other tests of peel strength after the thermal shock of soldering.

6.5 REMAINING PHYSICAL PROPERTY TESTS

6.5.1 Test Sample Preparation and Visual/Dimensional Examination

6.5.1.1 Specification References

GDP Drawings SP 133-4120 (Simple Linear Test Pattern), SP 133-5040 (two layer test patterns), SP 133-5053 (two layer coverlay), SP 133-5047 (four layer test patterns), SP 133-5063 (four layer coverlay), SP 133-5067 (pilot lot multilayer FPW actual harness design plus multiple test patterns), and SP 133-5055 (adhesive flow test pattern). GDP MPS T120.26H, MPS 120.38. For the pilot lot, use MIL-P-50884B, paragraphs 3.1 to 3.1.3, 3.5 to 3.5.8.1, 3.16 to 3.17, (each inclusive), and Test Method 4.7.1.

6.5.1.2 Test Equipment

As specified in GDP MPS T 120.26H, GDP MPS 120.38, and MIL-P-50884B, plus laminating presses as required.

6.5.1.3 Applicability: Some of the material tests required print and etch operations (for peel tests by Method C of IPC-TM 650-2.4.9, paragraph 5.3), plus laminations for the adhesive flow tests, as well as for the peel tests by Method A of IPC-TM 650-2.4.9 paragraphs 3.1 and 3.4. In preparation for some material tests, copper was first removed by etching (MPS T 120.26H), from copper clad laminates. All FPW samples, both the two layer and four layer test patterns, plus the multilayer FPW pilot lot, required the complete spectrum of FPW fabrication processing.

6.5.1.4 Sample Size

Most tests herein required five samples, frequently with multiple test patterns within each sample. The pilot lot, however, required six samples. Fewer samples were sometimes tested for information purposes, but the full sample will be desirable for the more critical final qualifications.

6.5.1.5 Sample Preparation

All samples were etched in accordance with GDP MPS T 120.26H for flex harnesses, with the following conditions and exceptions:

6.5.1.5.1 The etching solution was ferric chloride.

6.5.1.5.2 On certain specific clad laminate samples where total copper removal was required, without leaving any etched pattern, samples were not resist coated.

6.5.1.5.3 Routine print and etch operations were subjected to routine inspection surveillance.

6.5.1.5.4 In-process plating cross section tests (ARs) were postponed until the final trim operation, to include effects of coverlay lamination and pattern etching, since surplus test hole patterns were not always available to test completely twice.

6.5.1.6 Method

6.5.1.6.1 Etch Inner Layers

For the pilot lot only, after etching of inner layers, all test samples were examined in accordance with MIL-P-50884B, paragraphs 3.5.1, 3.5.2, 3.5.6.1, 3.5.7.1 and 3.5.7.2.

6.5.1.6.2 Bond Copper Clad Laminates

Following inner layer etch and inspection of all pilot lot test samples, the inner layers were bonded together as specified in drawing SP 133-5067, using the appropriate bondply material. After bonding of inner layers, all test samples were examined in accordance with MIL-P-50884B, paragraphs 3.5.6.1, 3.5.6.2, and 3.5.8.1.

6.5.1.6.3 Drilling and Plating of Pilot Lot Test Samples

After bonding, all pilot lot test samples were drilled and plated as specified in drawing SP 133-5067. Before plating, plasma smear removal was provided. Following plating, all samples were examined in accordance with MIL-P-50884B, paragraphs 3.5.5, 3.5.7 and 3.5.7.2.1.

6.5.1.6.4 Etching of Outer Layers

The outer layers of all pilot lot samples were etched in accordance with GDP-MPS T 120.26H for flex harnesses, using the test patterns described in SP 133-5067. Following etching, all samples were examined in accordance with MIL-P-50884B, paragraphs 3.5.1, 3.5.2, 3.5.5, 3.5.6.1, 3.5.7, 3.5.7.1, 3.5.7.2, and 3.5.7.2.1.

6.5.1.6.5 Bonding Coverlay

Following final etch of the pilot lot, the pre-drilled and trimmed coverlay were bonded to both sides of all test samples as specified in drawing SP 133-5067, using the appropriate coverlay material. Following bonding, all pilot lot samples were examined in accordance with MIL-P-50884B, paragraph 3.5.6.2, 3.5.7, 3.5.8, and 3.5.8.1.

6.5.1.6.6 Immersion Tin Plating or Solder Coating

After final bonding of the pilot lot samples, all exposed copper was plated as specified in GDP drawing SP 133-5067. Visual examination was as specified in drawing SP 133-5067.

6.5.1.6.7 Trimming of Pilot Lot Test Samples

All pilot lot test samples were trimmed (cut out) as specified in GDP drawing SP 133-5067. After trimming, all test samples were examined as specified in MIL-P-50884B, paragraph 3.5.3, and GDP drawing SP 133-5067. As specified in MIL-P-50884B, paragraph 3.5.4, the flexible printed wiring was not repaired if any delamination occurred during trimming or any part of this process.

6.5.1.6.8 Marking and Workmanship

All pilot lot tests samples were examined for marking and workmanship in accordance with MIL-P-50884B, paragraphs 3.16 and 3.17.

6.5.1.7 Requirements

6.5.1.7.1 Perform the specific examinations in accordance with the assembly procedure paragraphs.

6.5.1.7.2 Record all data in accordance with the requirements specified on the applicable data sheet.

6.5.1.8 Results

No difficulties were encountered in fabricating the print and etch and lamination samples for material tests. There were some irregularities encountered in the electroplating of test samples and pilot lot, due to schedule conflicts with a plant modernization changeover and the resultant problems. Only the pilot lot has special data sheets for preparation and examination. On this first pilot lot run, an oversight in making cut-outs in the coverlay before lamination necessitated a chemical etch through the polyimide as a repair procedure. Such a procedure was devised and worked well generally, except for a masking failure (leakage) on one area of one sample.

6.5.1.8 (Cont'd)

This still did not effect the electrical or physical tests of the FPW parts, but did effect the "Moisture Resistance" test, so that another sample (of the six pilot lot samples) was substituted. This is a non-standard operation and would not even effect yield under production conditions, so it is not considered a real failure. The other fabrication discrepancies were mostly involved with electroplating, and likewise are not normally problems related to the materials. One small problem with photoresist breakdown applied only to the larger diameter holes, which are used, but not as critical electrical interconnection paths. The overall results are that there were no problems which should be considered as of a potentially recurring, troublesome nature. Therefore a high yield is expected relative to previous Production experience, and it is expected that the losses will be cut in half. Some scrap, of course, is not material-oriented (i.e., they are labor oriented) and these will show little immediate change. It is reasonable, though, to hope that as the material-type losses are reduced, more attention will focus on labor type failures, and the improved morale with higher yields could lead to greater care, and even reduce, the labor-type failures (beyond the normal learning curve improvements).

6.5.1.9 Conclusions

FPW fabrication with polyimide-acrylic materials can provide higher process yields of good flexible printed wiring harnesses, with the processing methods now available, the majority of which are already standard practice with materials in present use.

6.5.2 <u>Copper Foil</u>

6.5.2.1 Specification Reference

MIL-P-13949D. TM6-133-128, Paragraph 17.

6.5.2.2 Test Equipment

In accordance with MIL-P-13949D.

6.5.2.3 Applicability

This is really just the standard incoming material quality inspection, common to high reliability (as opposed to commercial) printed wiring material specifications. It does not really fall in any of these four categories (peel strengths, mechanical, electrical or environmental tests) but is included here to avoid an extra major category. It obviously applies herein only to copper clad laminates (since copper foil alone is not included).

6.5.2.4 Sample Size

Sample size was in accordance with MIL-P-13949D, paragraph 3.3.1. Five samples of each tested material were subjected to the following copper foil tests.

6.5.2.5 Sample Preparation

Samples were prepared as specified in each individual test category.

6.5.2.6 Method

All samples were subjected to the test described below with the following conditions and exceptions.

6.5.2.6.1 Pits

The test for pits was performed in accordance with the requirements specified in MIL-P-13949D, paragraph 3.2.2.3.2.1 grade B, except the longest dimension allowed for pits was 0.005. The test method described in MIL-P-13949D, paragraph 4.6.2.1.2 was used.

6.5.2.6.2 Scratches

The test for scratches was performed in accordance with the requirements specified in MIL-P-13949D, paragraph 3.2.2.6. The test method described in MIL-P-13949D paragraph 4.6.2.1.3 was used.

6.5.2.6.3 Inclusions

The test for inclusions was performed in accordance with the requirements specified in MIL-P-13949D, paragraph 3.2.2.5. The test method described in MIL-P-133949D, paragraph 4.6.2.1.3 was used.

6.5.2.6.4 Surface Finish

The test for surface finish was performed in accordance with the requirements specified in MIL-P-13949D, paragraph 3.2.2.1. The test method described in MIL-P-13949D, paragraph 4.6.2.3 was used.

6.5.2.6.5 Purity

The tests for purity were performed in accordance with the requirements specified in MIL-P-13949D, paragraph 3.2.2. The test method described in MIL-P-13949D, paragraph 4.6.2.5 was used.

6.5.2.6.6 Copper-Foil Resistivity

The test for resistivity was performed in accordance with the requirements specified in MIL-P-13949D, paragraph 3.2.2. The test sample preparation and method described in MIL-P-13949D, paragraph 4.6.2.6 was used.

6.5.2.6.7 Copper-Foil Thickness

The test for copper-foil thickness was performed in accordance with the requirements specified in MIL-P-13949D, paragraph 3.2.2. The test method described in MIL-P-13949D, paragraph 4.6.2.7 was used.

6.5.2.7 Requirements

6.5.2.7.1 The requirements specified in MIL-P-13949D for each individual test shall be met unless a more stringent requirement is set forth in this test procedur[illegible]

6.5.2.7.2 [illegible] ll data in accordance with the requirement specified on the appli[illegible] data sheet.

6.5.2.8 Results

All three vendors provided satisfactory copper clad laminates with respect to copper foil quality.

6.5.2.9 Conclusions

This test was not a factor in the material selection, but it is of course a necessary continuing incoming material qualification. Many of these tests are visually obvious, and rejects would be reported back from production even if they should escape the governmental standard Quality Assurance incoming spot checks.

6.5.3 <u>Solderability</u>

6.5.3.1 Specification References

IPC-TM 650-2.4.13, except using test pattern "A" (of drawing SP 133-5040 for two layer FPW, of drawing SP 133-5047 for multilayer FPW, and of drawing SP 133-5067 for multilayer pilot lot FPW).

6.5.3.2 Test Equipment

As specified in IPC-TM 650-2.4.13, paragraph 4.0.

6.5.3.3 Applicability

The solderability tests were applied to all FPW herein (two layer, four layer and multilayer pilot lot test patterns). They are obviously not applicable to any of the dielectric materials, and failure is too unlikely to justify test time for any of the copper clad materials.

6.5.3.4 Sample Size

Five samples of test pattern "A", which were fabricated in accordance with Section 8 herein, and were previously tested in accordance with paragraph 6.7.3 (dielectric withstanding voltage) herein, were subjected to the following solderability tests.

6.5.3.5 Sample Preparation

All test samples were prepared in accordance with IPC-TM 650-2.4.13, paragraph 5.1, on one side only, prior to subjecting samples to the solderability test.

6.5.3.6 Method

All five test samples, on the prepared side only, were subjected to the solderability tests specified in IPC-TM 650-2.4.13, paragraph 5.2.

6.5.3.7 Requirements

6.5.3.7.1 Examine for wetting, blistering, delamination or measling at a minimum of 100X magnification.

6.5.3.7.2 The flexible printed wiring shall show free solder wetting of at least 90% of the conductor area not covered by insulating material or adhesive.

6.5.3.7.3 Record all data in accordance with the requirements specified on the applicable data sheet.

6.5.3.8 Results

This test is applicable only to the FPW test pattern, and only acrylic FPW were fabricated and tested in this program. All samples tested passed this solderability test. This test has no bearing on the selection among materials, but instead merely insured against the possibility of a solderability problem on the acrylic material selected from the materials evaluation tests.

6.5.3.9 Conclusions

There is no solderability problem with the acrylic materials. Note that this does not mean that there can be no "soldering" problems, but only that the copper surface is capable of being soldered after proper cleaning.

6.5.4 Curl Resistance

6.5.4.1 Specification Reference

IPC-TM 650-2.4.22 Indicator Height Gauge Test (except with concave surface up), and GDP-TM6-133 paragraph 36.

6.5.4.2 Test Equipment

As specified in IPC-TM 650-2.4.22 paragraph 4.0.

6.5.4.3 Applicability

The curl resistance test was planned for the copper clad laminates and the adhesive coated insulation sheets, but not for adhesive film (as too flexible) or fabricated FPW. The FPW are presumably flexible anyway, by definition, and have been through so many processing operations that those would probably affect their curling tendency, at any given time, much more than the starting material. However, two of the three clad laminate sources provided sheets rather than rolls of clad laminates, so obviously only the rolls (with phenolic butyral) would have significant curl, and that disappears sufficiently after flat storage in the tightly-taped packages prepared for the drilling operations. Since no significant problem remains with clad laminates, they were not tested for curl resistance. The coverlay especially (and bondply slightly) used to have an important curling problem in Production, caused by their rolling up when the release sheets were removed, so that practical handling became difficult. Since a change of release sheet materials had solved this problem for the phenolic butyral materials, and the problem never appeared from the other two material sources, all of the curl resistance tests were

6.5.4.3 Applicability (Cont'd)

abandoned herein. However, the requirements are still listed herein since the test is valuable, as a specification requirement for new material applicants, or if a future material change or shortage causes a recurrence of the curl problem.

6.5.4.4 Sample Size

Five samples of each tested material would have been subjected to the following curl resistance test, if it had not been cancelled.

6.5.4.5 Sample Preparation

Samples would have been tested as received using standard material size of 12 inches square.

6.5.4.6 Method

All test samples would have been subjected to the curl resistance test specified in IPC-TM 650-2.4.22, paragraph 5.1 (Reference indicator height gauge test) except with concave surface up.

6.5.4.7 Requirements

6.5.4.7.1 The insulation sheet shall exhibit a 5 inch maximum rise, and shall not curl upon itself.

6.5.4.7.2 Record all data in accordance with the requirements specified on the applicable data sheet.

6.5.4.8 Results

As indicated above, none of these tests were needed, so that none were performed, yielding no results.

6.5.4.9 Conclusions

Visual observation of all of the materials included in this test program indicated that no significant curl resistance problem remains on any of these materials.

6.5.5 Adhesive Flow

6.5.5.1 Specification Reference

GDP TM 6-133-128, paragraphs 38.0 and 51.0. GDP Drawing SP 133-5055.

6.5.5.2 Test Equipment

Laminating Press, Microscope, Cross-Sectioning Equipment for Photomicrographic Mounts, and Trim Template SP 133-5055.

6.5.5.3 Applicability

Adhesive flow was tested on both the phenolic butyral and the acrylic adhesive systems in this program, but only on the adhesive coated insulation sheets and the adhesive films. Its effect could probably be measured upon any FPW with coverlay, at the drilled coverlay holes used to expose plated through holes for soldering of connectors or other leads or terminals. It should be fairly consistent for the total solids type acrylic materials under given laminating temperature and pressure conditions, although solvent-type adhesives (such as phenolic butyral) should be expected to vary somewhat with adhesive age and corresponding loss of solvents. This test was an after-thought not in the original "Test and Evaluation Plan" (Reference 7). It was added to determine whether a real Production problem in FPW fabrication, (involving hand rework of a few problem part designs to clean up excessive adhesive overflow onto some bonding pads from the encircling coverlay holes) would be aggravated, unchanged, or resolved by other material applicants.

6.5.5.4 Sample Size

Five assemblies each of the materials being tested were used for the adhesive flow tests. Each test pattern is eight inches square.

6.5.5.5 Sample Preparation

Two oz. clad laminate was obtained by electroplating the 1 oz. copper laminate from the adhesive system under test, up to 2 oz. copper thickness (0.0028 inch total copper/side). Copper clad laminate was then fabricated by standard print and etch, using test pattern SP 133-5055.

6.5.5.6 Method

Using the SP 133-5055 test pattern and the vendor's recommended lamination process, the insulation sheet was bonded to the etched copper pattern (after the etched detail was cleaned and baked at 250°F. for one hour). The etched lines were cross-sectioned perpendicular to the longitudinal axis of the lines, and examined at a magnification of 100 x for full adhesive flow. All four hole patterns of each hole size, and the tapered slot, were examined for excessive adhesive flow.

6.5.5.7 Requirement

6.5.5.7.1 The adhesive shall show full flow into all areas between 0.010 inch wide paths on 0.025 centers and 0.025 wide paths on 0.050 centers which have been etched through 2 ounce copper. The adhesive shall not flow more than 0.005 inch from the edge of a hole or slot.

6.5.5.7.2 Record all data as specified on the applicable data sheet.

6.5.5.8 Results

The data sheets on both material types show no failures, to the specified limit of 0.005 inch flow per edge. The phenolic butyral samples did show an uneven flow around the holes, very close to the 0.005 inch limit. The acrylic shows relatively little adhesive flow, so that it should eliminate the Production problem mentioned earlier with excessive adhesive flow requiring manual cleanup. Some additional tests were done at half the normal laminating pressures for each material. This reduced but did not eliminate the adhesive flow problem of the phenolic butyral. It also produced inadequate flow into the fillets of the etched circuitry with the acrylic adhesive.

6.5.5.9 Conclusions

The acrylic materials will resolve the present problem of excessive adhesive flow, but caution is necessary to avoid reducing the laminating pressure too far, or failing to provide sufficient rubber to prevent low pressure spots, to be sure that voids do not appear. The vendor recommended pressures for acrylic materials is about half of that recommended for phenolic butyral, but lowering the pressure for phenolic butyral laminations below 600 psi sometimes creates other problems, without resolving the adhesive flow problem.

6.5.6 Dimensional Stability After Etch

This property is moderately critical on clad laminates for two layer FPW in order to obtain adequate alignment of coverlay (when required). The acceptable dimensional change per inch is reduced as part size increases, as the difference between hole and pad size decreases, and as number of layers increase. For multilayer FPW, this property is even more important, because etched details must be aligned to each other, as well as to the coverlay, and two laminations are involved. It is less critical when two details are etched on one side only before lamination of a four layer FPW, than when both sides of the same detail (double clad laminate) are etched before a multilayer lamination. Superior design of trim area artwork and tooling can alleviate the problem somewhat if it remains, and the X-ray or close examination of multilayer laminates after drilling can quantify the problem and identify rejects before further labor expenditure on each individual panel. While this has been a serious problem in the past, improvements in the vendor materials, the lamination tooling, the lamination parameters (pressure and temperature), part designs, and photographic working tools have already greatly reduced alignment problems on FPW.

6.5.6.1 Specification References

IPC-TM 650 - 2.2.4, Method B, and GDP-TM 6-133-128, paragraph 25.0.

6.5.6.2 Test Equipment

As specified in IPC-TM 650 - 2.2.4, paragraph 4.0.

6.5.6.3 Applicability

Since this is stability after etch, it applies directly only to the clad laminate material. It could probably be measured on etched details for the FPW, but it does show up more practically on those as the FPW hole-to-pad alignment, layer-to-layer pad alignment, and coverlay hole-to-pad alignment. Since these are all subject to normal inspection procedures, a specific separate dimensional stability test was presumably not justified for FPW.

6.5.6.4 Sample Size

Five samples of each tested material were subjected to the following test for dimensional stability after etch.

6.5.6.5 Sample Preparation

All five samples of each material to be tested were formed in accordance with IPC-TM 650-2.2.4, paragraph 3.0, prior to testing.

6.5.6.6 Method

All samples herein for dimensional stability after etch were subjected to the test in accordance with IPC-TM 650-2.2.4, paragraph 5.2 (Method B). After initial measurements, all samples were etched in accordance with GDP MPS T120.26H for flex harness, at an etching temperature of 130 $\pm$ 5°F, and remeasured for comparison of shrinkage.

6.5.6.7 Requirements

6.5.6.7.1 The copper clad laminate shall exhibit 0.002 inches/inch maximum shrinkage due to total metal removal.

6.5.6.7.2 Record all data in accordance with the requirements specified on the applicable data sheet.

6.5.6.8 Results

Clad materials with both the acrylic and phenolic butyral adhesive systems were tested, and both passed without any significant difference in results.

6.5.6.9 Conclusions

This is a valuable incoming material inspection qualification test , though it may not be necessary to apply it routinely until an otherwise unexplained alignment problem appears, simply as a cost trade-off between yield and incoming inspection costs. It is of course essential in any new material qualification.

6.5.7 Dimensional Stability After Etch Plus Thermal Exposure

This test is designed to predict the potential effects of oven drying and hot lamination operations on different materials. It does not precisely duplicate processing conditions, in that the restraints of lamination tooling pins and lamination pressure during the heating cycle are not reproduced, but those effects are measured in a very practical manner in the alignment requirements of the FPW test patterns and the Pilot Lot of multilayer FPW. As a standard IPC test, it provides data which may be correlated within the industry more precisely than would a test designed for our own plant's processing parameters.

6.5.7.1 Specification References

IPC-TM 650-2.2.4, Method C, and GDP-TM 6-133-128.

6.5.7.2 Test Equipment

As specified in IPC-TM 650-2.2.4, paragraph 4.0.

6.5.7.3 Applicability

Since this is also stability after etch, with an added thermal treatment, it has the same samples and applicability as the preceding test, paragraph 6.5.6.3. This test applies only to clad laminate, but similar effects are noted in results on all FPW fabrication.

6.5.7.4 Sample Size

This is a continuation of the testing on the same samples listed in the preceding test of paragraph 6.5.6.4.

6.5.7.5 Sample Preparation

Prior testing of preceding section 6.5.6.

6.5.7.6 Method

All samples tested herein for dimensional stability after etch plus thermal exposure were subjected to the test in accordance with IPC-TM 650-2.2.4, paragraph 5.3 (Method C). After measurements before and after etch were taken and recorded on the data sheet per the preceding test, paragraph 6.5.6.6, all samples were placed in an oven in accordance with IPC-TM 650-2.2.4, paragraph 5.3 (Method C). After thermal exposure, samples were again measured and the data recorded on the applicable data sheet.

6.5.7.7 Requirements

6.5.7.7.1 The copper clad laminate shall exhibit .002 inches/inch maximum shrinkage due to total metal removal and thermal exposure.

6.5.7.7.2 Record all data in accordance with the requirement specified on the applicable data sheet.

6.4.7.8 Results

Clad materials with the acrylic and phenolic butyral adhesive system both showed rather marginal results relative to the above requirement, but both passed. While the maximum dimensional changes were somewhat greater with the phenolic butyral samples, the difference did not appear significant, and both materials appear adequate in this respect, although further improvement is desirable for both.

6.5.7.9 Conclusions and Recommendations

This is a valuable continuation of the preceding test (See paragraph 6.5.6.9) and probably should be included wherever the test for dimensional stability after etch is used on clad laminates.

6.5.8 <u>Dimensional Stability After Thermal Exposure</u>

6.5.8.1 Specification References

IPC-TM 650-2.2.4 Method A, and GDP TM 6-133-128, paragraph 35.

6.5.8.2 Test Equipment

As specified in IPC-TM 650-2.2.4 paragraph 4.0.

6.5.8.3 Applicability

This is obviously related to the preceding paragraphs 6.5.6 and 6.5.7, but applies instead to adhesive coated insulation sheet, before it has been laminated to any copper which could be etched. In the use of coverlay, this test gives some clue to the probability of shrinkage during early stages of lamination, but it is not a perfect correlation, because tooling pins and applied pressure normally restrain the coverlay before it is heated appreciably. For bondply, which usually has only tooling holes drilled before lamination, and thereafter is restrained by the rest of the laminate before alignment becomes critical, this test is even less important, at least as used in present designs here.

6.5.8.3 Applicability (Cont'd)

Film adhesive, at least at the 0.001 inch thickness available for this program, is too soft and flexible to yield accurate or significant results on this test, and is normally constrained in lamination without initial holes except for the tooling holes which provide that constraint.

6.5.8.4 Sample Size

Five samples of each tested material were subjected to the following test for dimensional stability after thermal exposure.

6.5.8.5 Sample Preparation

All five samples of each material to be tested were formed in accordance with IPC-TM 650-2.2.4 paragraph 3.0. Sample measurements were taken and recorded on data sheets prior to subjecting samples to temperature.

6.5.8.6 Method

All test samples were subjected to the dimensional stability test described in IPC-TM 650-2.2.4, paragraph 5.0 (Method A).

6.5.8.7 Requirements

6.5.8.7.1 The insulation sheet shall exhibit .002 inches/inch maximum shrinkage due to thermal exposure.

6.5.8.7.2 Record all data in accordance with the requirements specified on the applicable data sheet.

6.5.8.8 Results

The acrylic bondply failed the above requirement by a factor of two, while the acrylic coverlay, for which dimensional stability is much more important, passed easily. The phenolic butyral, in marked contrast, passed the bondply requirement marginally, but failed the more important coverlay requirement by 50%. With both materials, the major variations were in the transverse (as opposed to machine) direction.

6.5.8.9 Conclusions and Recommendations

The requirements on this test should probably differentiate between coverlay and bondply, and should probably be increased to allow for greater shrinkage on both, and especially on bondply. This requirement should be less restrictive and is considered less important than the corresponding dimensional stability of clad materials. Both materials are probably adequate with regard to this test, though the acrylic had the advantage of better results in the more critical material.

6.5.9 <u>Plating Thickness of Plated Through Holes</u>

6.5.9.1 Specification References

IPC-TM 650-2.2.13, except using test pattern "E" (of drawing SP 133-5040 for two layer FPW, SP 133-5047 for four layer FPW, and SP 133-5067 for the pilot lot multilayer FPW). GDP TM 6-133-164, (paragraph 11),-168 (paragraph 11) and-174 (paragraph 16) for the 2 layer, 4 layer and pilot lot respectively. GDP MPS 90-69E (only if edge delamination repair should be needed).

6.5.9.2 Test Equipment

As specified in IPC-TM 650-2.2.13, paragraph 4.0.

6.5.9.3 Applicability: The plating thickness is obviously only applicable to plated parts, and therefore only to the FPW in this program. Of course, plating thickness is simply a process variable depending upon the plating time and current density, except in the plated through holes (where throwing power, hole diameter, laminate thickness, smear removal and drilling inperfections may influence uniformity). After adequate holes are obtained, if in-process tests show inadequate plating thickness, the parts are simply reactivated and electroplated with the required additional thickness of copper. On this test program, reduced thickness might endanger some electrical tests but would be expected to improve results somewhat on flexural fatigue and folding endurance tests, which apply only to the 2 layer and 4 layer FPW tests.

6.5.9.4 Sample Size

Test pattern "E" (with 24 holes per sample) of five samples of 2 layer FPW (drawing SP 133-5040), test pattern "E" (with 24 holes per sample) of five samples of four layer FPW (drawing SP 133-5047),

6.5.9.4 Sample Size (Cont'd)

and the four holes per sample (identified by coordinates as J57-11, J57-15, J1-31, and J3-15) of four samples of the multilayer pilot lot FPW (drawing SP-133-5067) identified as -1, -2, -5 and -6, after fabrication in accordance with Section 8 herein, were subjected to the following test for plating thickness of plated through holes.

6.5.9.5 Sample Preparation

6.5.9.5.1 All test samples were prepared and conditioned in accordance with IPC-TM 650-2.2.13, paragraph 5.1, prior to testing.

6.5.9.5.2 The surface of all samples were prepared in accordance with IPC-TM 650-2.2.13, paragraph 5.3.

6.5.9.5.3 If any delamination had occurred during the cut-out process, except on the pilot lot, the edges would have been repaired in accordance with GDP MPS-90.69, and the repair would have been noted on the applicable data sheet.

6.5.9.6 Method

After sample preparation, conditioning, and surface preparation per IPC-TM 650-2.2.13 paragraphs 5.2 and 5.3, each hole being tested was examined at a minimum of 100 x magnification, and only the thinnest measurement obtained was recorded. Paragraph 5.4 of IPC-TM 650-2.2.13 does not apply for sample measurement. On the pilot lot multilayer FPW, the four holes on each of the four test samples were subjected to the plating thickness tests in accordance with MIL-P-50884B paragraph 4.7.11.

6.5.9.7 Requirements

6.5.9.7.1 For the pilot lot multilayer FPW only, a solder coating thickness of 0.0003 inch thick minimum, or an immersion tin plating of 0.000020 inch thick minimum, both on the conductors and in the holes, is a requirement. In this test program, immersion tin was used throughout, with no solder plating.

6.5.9.7.2 For all FPW, the thickness of the copper plating in the holes shall be 0.001 inch minimum.

6.5.9.7.3 There shall be no cracks, voids, adhesive smear, nodules, separation of conductor interfaces, or excessive etchback of the base laminate in the plated through holes. Laminate voids shall not be permitted.

6.5.9.8 Results

Only acrylic FPW are included in these tests, but a long history of Production experience has been available for the phenolic butyral adhesive system.

6.5.9.8.1 Two Layer FPW

These were processed during a difficult period of plating line changeover in a plant modernization, and as such were subject to abnormal difficulties related to schedule priorities and processing problems. The microscopic cross sections of plated through holes on these test panels revealed organic inclusions which appear to be of acrylic origin in all holes, and therefore all failed that inspection parameter, but there were no plating voids and all thicknesses were uniform and adequate. Three of the samples even show evidence of poor copper to-copper plating adhesion, which is now rare. It is possible that this may have had an adverse effect upon the terminal area bond strength. However, multiple cross sections of other two layer acrylic test samples and the results with the much more difficult multilayer plated through holes indicate that this was an abnormal result rather than a legitimate problem. This will be confirmed manyfold during the follow-on fabrication of FPW in the transition to acrylic materials, since such cross sections are a routine part of FPW fabrication here.

6.5.9.8.2 Four Layer MLF

Six hole diameters are included in both the two layer FPW and four layer MLF, with the largest two sizes of one quarter inch and three sixteenths inch diameters, considerably larger than any which GDP FPW designs currently depend upon for electrical interconnection. On this set of five multilayer FPW, unusual plating roughness apparently led to some photoresist breakdown which in turn caused some etched plating voids in many of the larger diameter holes. The four smaller hole diameters, including three normally used for electrical interconnection, passed on 19 of the 20 holes tested, and was marginal (at 90% of requirement) on the remaining hole. All hole sizes were reported to exhibit some degree of "smiles" in the through hole copper plating. While this is undesirable, it is a relative thing, and compared to normal Production state-of-the-art on current phenolic butyral FPW, these test samples were very good.

6.5.9.8.3 Pilot Lot of Multilayer FPW

Four holes each of four pilot lot FPW samples were tested. Immersion tin thickness on both holes and conductors all passed, but the minimum thickness of copper plating in the plated through holes did fail on two of the four samples, with one at 0.0009 and the other ranging from 0.0007 to 0.0009 where 0.0010 is required. These failures would normally be detected in production by the routine in-process testing (which was not used on the test samples, in order to preserve all the test coupons until after all processing was completed). In Production, thin plating would merely lead to reactivation and additional plating, rather than to rejection of parts. Since the pilot lot tests do not include flexural fatigue or folding endurance, this thinner plating should really have no significant effect on any of the results. It is therefore embarrasing, but otherwise does not detract from the success of the pilot lot made from polyimide acrylic materials.

6.5.9.9 Conclusions

While electroplating success was not a highlight of the fabrication of the polyimide-acrylic materials into two layer, four layer, and multilayer pilot lot FPW, the smear removal and electroless plating were highly successful, and there seems no reason to ascribe any plating problems which still remain to the acrylic materials, when the plating follows the plasma smear removal process. While through hole plating is still imperfect, it shows continuing improvement over past results in adhesion, elongation, uniformity, and freedom from voids and cracks.

6.6 ENVIRONMENTAL TESTS

6.6.1 Thermal Shock

6.6.1.1 Specification References

MIL-P-50884B, paragraphs 3.9 and 4.7.5 (except using test pattern G of drawing SP 133-5040 for two layer FPW, test pattern G of drawing SP 133-5047 for four layer FPW, and test pattern E of drawing SP 133-5067 for the multilayer pilot lot FPW) after they have been previously tested for continuity in accordance with paragraph 6.7.1.6.1 herein. MIL-STD-202E, Method 107. GDP TM 6-133 - 164 (paragraph 17), -168 (paragraph 17), and -174 (paragraph 10).

6.6.1.2 Test Equipment

As specified in MIL-STD-202E, Method 107, paragraph 2.0.

6.6.1.3 Applicability

Thermal Shock tests were performed on all three categories (two layer, four layer, and multilayer pilot lots) of FPW in this program, in conjunction with, but after, the electrical continuity tests on the same test parts. Thermal shock tests would not be too significant in materials tests, since the plated through holes are the most sensitive interconnect in thermal shock tests. However, thermal shock tests are probably less important in FPW than in ordering epoxy glass printed wiring boards, since the latter are subject to greater Z-axis thermal expansion at the plated through holes. Nevertheless this is still an excellent test to determine quality of a multilayer plated through hole system, since it checks both lamination and plating integrity.

6.6.1.4 Sample Size

Test pattern G of five samples each of two layer FPW and four layer FPW, and test pattern E of the two test samples of the multilayer pilot lot FPW which are identified as SP 133-5067 E-3 and -4, were tested for the effects of thermal shock.

6.6.1.5 Sample Preparation

Each sample tested for thermal shock was previously subjected to the continuity tests specified in paragraph 6.7.1 following herein. No other special sample preparation is required for this thermal shock test.

6.6.1.6 Method

6.6.1.6.1 The testing requirements for thermal shock of two layer and four layer FPW have been accomplished as part of the testing specified in paragraph 6.7.1 herein (continuity). For the multilayer pilot lot FPW, the two test samples were subjected to the thermal shock test as specified in MIL-P-50884B, paragraph 4.7.5.

6.6.1.6.2 The testing results for thermal shock were recorded on the same applicable data sheet used for recording the continuity results.

6.6.1.7 Requirement

6.6.1.7.1 The flexible printed wiring shall show no evidence of delamination or other damage after exposure to thermal shock, in accordance with MIL-P-50884 paragraph 4.7.5, except for above changes in test patterns.

6.6.1.7.2 An additional requirement was applied to the 2 layer and four layer test pattern FPWs, that after conversion of all continuity and thermal shock test data to its 20°C resistance equivalent, Rc, the change between the initial room ambient measurements and the post thermal shock examination after returning to room ambient shall not exceed ± 10% of the initial Rc.

6.6.1.7.3 The test results for thermal shock shall be recorded on the applicable data sheet for continuity testing, paragraph 6.7.1 following herein.

6.6.1.8 Results

Since these tests apply only to FPW, only acrylic FPW results are available from this program.

6.6.1.8.1 Two Layer FPW

The changes after thermal shock on the four measured samples ranged between zero and four percent, with the average below two percent. There were no failures.

6.6.1.8.2 Four layer FPW

The changes after thermal shock on five samples were all below one percent, which seems exceptional. There were no failures.

6.6.1.8.3 Multilayer Pilot Lot FPW

The pilot lot requirements for thermal shock were passed completely, but do not involve the percent of change evaluation.

6.6.1.9 Conclusions

All acrylic material FPW tested in the program, including those with some noted plating deficiencies, easily passed the thermal shock test requirements herein. There is a possibility that the FPW improvement resulting from the material changes recommended from this project may permit upgrading the MIL-P-50884 paragraph 4.7.5 requirements in the future to insure higher quality FPW products for defense.

6.6.2 Moisture Resistance

6.6.2.1 Specification References

MIL-P-50884, paragraph 3.11 and paragraph 4.7.7, except using test pattern B (of drawing SP 133-5040 for two layer FPW, of drawing SP 133-5047 for four layer FPW , and of drawing SP 133-5067 for pilot lot of multilayer FPW). GDP TM 6-133-164 (paragraph 18), -168 (paragraph 18), and -174 (paragraph 12). MIL-STD-202E, Methods 106 and 302. IPC-TM 650-2.5.9, paragraph 5.2.4.

6.6.2.2 Test Equipment

As specified in MIL-STD-202E, Method 106D paragraph 2.0, and Method 302, paragraph 2.0.

6.6.2.3 Applicability

This moisture resistance test is only applied to the FPW, and therefore it has only been applied to parts fabricated with acrylic adhesive materials in this program. It is equally applicable to any other FPW.

6.6.2.4 Sample Size

Five samples of test pattern B (of drawing SP 133-5040 for two layer FPW, and of drawing SP 133-5047 for four layer FPW) and two samples of test pattern B, identified as -5 and -6 (both of drawing SP 133-5067) were subjected to the following moisture resistance tests.

6.6.2.5 Sample Preparation

All samples tested for moisture resistance herein were fabricated in accordance with Section 8 herein, and were previously tested for insulation resistance in accordance with paragraph 6.7.2 (following herein), prior to testing for moisture resistance.

6.6.2.6 Methods

6.6.2.6.1 Moisture Resistance

After completing the insulation resistance tests in accordance with paragraph 6.7.2 following herein, all samples to be tested were next subjected to the moisture resistance tests specified in MIL-P-50884B, paragraph 4.7.7.

6.6.2.6.2 Post Humidity Insulation Resistance

Following the moisture exposure, all samples to be tested were subjected to insulation resistance tests, as specified in MIL-P-50884, paragraph 4.7.7 (c) on the two pilot lot pattern B samples, and as specified in MIL-P-50884B, paragraph 4.7.6, with the following conditions and exceptions on the samples of 2 layer and 4 layer FPW.

6.6.2.6.2.1 The test pattern description in IPC-TM 650-518, test pattern D, was used for terminal identification.

6.6.2.6.2.2 Measurements were taken in accordance with IPC-TM 650-2.5.9, paragraph 5.2.4.

6.6.2.7 Requirements

6.6.2.7.1 Following the moisture resistance tests, the exposed flexible printed wiring shall show no evidence of delamination or corrosion of conductors.

6.6.2.7.2 When samples are tested as specified following moisture resistance, the insulation resistance between conductors shall not be less than 50 megohms.

6.6.2.7.3 Record all data in accordance with the requirements specified on the applicable data sheet.

6.6.2.8 Results

These moisture resistance tests were scheduled in this program only on acrylic-polyimide FPW. There were no failures in any of these moisture resistance tests (which includes delamination, corrosion, and resistance).

6.6.2.8.1 Two Layer FPW

Post-moisture resistance readings ranged from 90 to 850 megohms, as compared to insulation resistance (pre-humidity) of 200 to 800 megohms, all well above the suggested requirements.

6.6.2.8.2 Four Layer FPW

Post-moisture resistance readings ranged from 140 to 550 megohms, as compared to insulation resistance (pre-humidity) of 160 to 1,000 megohms, all well above the suggested requirements.

6.6.2.8.3 Multilayer Pilot Lot FPW

Both test samples passed all requirements, both for this moisture resistance test (50 megohms minimum) and for the preceding test for insulation resistance (100 megohms minimum).

6.6.2.9 Conclusions

The FPW fabricated for this program from polyimide-acrylic materials passed all moisture resistance tests with a good safety margin, even though some of the plated through holes on these samples were imperfect. With the improved plating expected in future Production, passing this test routinely should be no problem other than testing costs.

6.6.3 <u>Moisture Absorption</u>

6.6.3.1 Specification References

IPC-TM 650-2.6.2, TM 6-133-128, paragraph 15.

6.6.3.2 Test Equipment

As specified in IPC-TM 650-2.6.2.

6.6.3.3 Applicability

Moisture absorption is primarily a function typical more of the polyimide, which is common to all of the material systems herein, than of the different adhesives involved (at least after curing), and it is likewise more of a function of the specific history (storage time, and relative humidity during that time) prior to this test. The uncured adhesives of bondply, coverlay and film adhesive might also absorb humidity, but such tests were not included in this program, and results would depend on their past history also. In FPW, which were not tested under this category, results would be varied greatly by oven baking such as that normally preceding assembly soldering operations.

6.6.3.4 Sample Size

Five samples of each tested material were subjected to the following moisture absorption test. All test samples were cut to the size specified in IPC-TM 650-2.6.2, paragraph 3.0. prior to testing.

6.6.3.5 Sample Preparation

All test samples being subjected to this test were etched in accordance with paragraph 8.1.1 herein prior to the start of testing. All test samples were prepared in accordance with IPC-TM 650-2.6.2, paragraph 5.1.

6.6.3.6 Method

6.6.3.6.1 All test samples were tested in accordance with IPC-TM 650-2.6.2, paragraph 5.2.

6.6.3.6.2 The moisture absorption was calculated in accordance with IPC-TM 650-2.6.2, paragraph 5.3.

6.6.3.7 Requirements

6.6.3.7.1 The moisture absorption shall be 4.0% maximum.

6.6.3.7.2 Record all data in accordance with the requirements specified on the applicable data sheet.

6.6.3.8 Results

Acrylic and phenolic butyral clad laminate were both tested, after removing copper by etching. The acrylic averaged 3.8%, fairly close to the 4.0 maximum, while the phenolic butyral averaged only 2.2%.

6.6.3.9 Conclusions

The phenolic butyral results showed considerably less moisture absorption but both materials passed the requirement, and repeated tests over a longer time period would probably be necessary to establish whether the difference is significant. The peel strength tests seem to indicate that the levels of moisture observed were not harmful, and the pre-assembly baking operations should greatly reduce the moisture content of FPW anyway.

6.6.4 <u>Fungus Resistance</u>

6.6.4.1 Specification References

CCC-T-191B, Method 5762. GDP TM-6-133-128, paragraph 16.

6.6.4.2 Method

Each vendor certification that five samples of this type of copper clad laminate material have successfully passed, after etching, the fungus resistance test specified in CCC-T-191B, method 5762, will satisfy the test requirements.

6.6.4.3 Requirements

6.6.4.3.1 The samples shall exhibit no evidence of sustaining or promoting the growth of fungi after 12 month soil burial.

6.6.4.3.2 Witnessing signature of vendor certification is required on the applicable data sheet.

6.6.4.4 Results and Conclusions

This test was included in the "Test and Evaluation Plan" (reference 7) in order to comply with an anticipated future requirement of CCC-T-191B. However, even then it only proposed certification by the vendor. Since the test requires one year of soil burial, requiring such test was really beyond the practical scope of a program of this limited size.

6.7 ELECTRICAL TESTS

6.7.1 Electrical Continuity

6.7.1.1 Specification References

MIL-P-50884B, paragraph 4.7.4.1, except using test pattern G (of GD/P drawing SP 133-5040 for 2 layer FPW, and of drawing SP 133-5047 for four layer FPW). MIL-P-50884B. paragraphs 3.8.2 (Class 2) and 4.7.4.2 except using both test patterns D and E of drawing SP 133-5067. MIL-STD-202E, Method 107. GDP TM 6-133-164 (paragraph 8), - 168 (paragraph 8) and -174 (paragraph 9). GDP/MPS 80.69E.

6.7.1.2 Test Equipment

As specified in MIL-P-50884, paragraph 4.7.4.2, and MIL-STD-202E, paragraph 2.

6.7.1.3 Applicability

Electrical continuity tests could be performed on a simple one layer etched line pattern on copper clad laminate. but this would only be a test of "print and etch" processing, rather than one effected by material selection. Continuity is much more significant on a plated through hole FPW test pattern and is of course a practical requirement of every interconnected circuit in production FPW. Only acrylic FPW were included in this test program and its results.

6.7.1.4 Sample Size

Test pattern G of five samples each of the two layer and four layer FPW, test pattern D of two samples plus test pattern E of six samples of the multilayer pilot lot FPW, all of which were fabricated in accordance with Section 8 herein, were used for the following continuity tests. The test pattern D used for this test was removed from the basic pilot lot test pattern assemblies identified as -3 and -4 of SP 133-5067.

6.7.1.5 Sample Preparation

6.7.1.5.1 Care was taken to remove the specified test patterns from the laminated assemblies without causing damage to the surrounding test patterns.

6.7.1.5.2 If delamination had occurred during the cut-out process, other than on the Pilot Lot, the edges would have been repaired in accordance with GDP MPS 90.96E, and the repair would have been noted on the corresponding data sheet for this test. No such delaminations occurred on these acrylic adhesive samples.

6.7.1.6 Method

6.7.1.6.1 Two and Four Layer MLF

Pattern G of five samples of each were subjected to the following tests in the sequential order listed.

6.7.1.6.1.1 Initial electrical tests

The resistance and temperature of the test samples were measured in accordance with MIL-P-50884B, paragraph 4.7.4.1 (a). then readings were converted to the 20°C reference temperature.

6.7.1.6.1.2 Thermal Shock

(Used also in paragraph 6.6.1 herein). The test samples were subjected to the thermal shock test in accordance with MIL-P-50884B, paragraphs 4.7.5.1 (b and c). After the samples were returned to room ambient, the visual and electrical tests specified were performed. The 20°C conversion of post thermal shock resistance test readings were compared to the 20°C conversion of resistance readings from the initial electrical tests.

6.7.1.6.1.3 Low Temperature Exposure

All five tests samples of both the two layer and four layer FPW were then subjected to the low temperature test specified in MIL-P-50884B, paragraph 4.7.4.1 (d). The electrical test specified was performed while at the low temperature. Those resistance readings taken while at the low temperature were compared to the resistance readings derived from the initial resistance tests after all readings were converted back to the 20°C reference temperature.

6.7.1.6.1.4 Ambient Stabilization

After low temperature exposure, the test samples were returned to ambient room temperature and were stabilized for a minimum of 5 minutes.

6.7.1.6.1.5 High Temperature

All five test samples were subjected to the high temperature test specified in MIL-P-50884B, paragraph 4.7.4.1 (e). While at the elevated temperature, the specified electrical test was performed. Those resistance readings taken while at the high temperature, after conversion to the 20°C reference temperature, were compared to the resistance readings derived from the initial resistance tests that were converted to the 20°C reference temperature.

6.7.1.6.2 Method for Multilayer Pilot Lot FPW

The continuity tests were divided into two separate test groups which conformed to the following.

6.7.1.6.2.1 Test Group I

All six patterns identified with an "E" from drawing SP 133-5067 were continuity tested in accordance with MIL-P-50884B, paragraph 4.7.4.2 (class 2), and the series resistance requirements specified on drawing SP 133-5067.

6.7.1.6.2.2 Test Group 2

The "D" test patterns from the two samples of drawing SP 133-5067 identified as -3 and -4 were continuity tested in accordance with MIL-P-50884B, paragraph 4.7.4.2 (class 2), and the series resistance requirements specified on drawing SP 133-5067.

6.7.1.7 Requirements

6.7.1.7.1 After environmental exposure, the resistance measurements of all test patterns from the 2 layer and 4 layer MLF identified with a "G" shall not change by more than $\pm$ 10% from the initial resistance, when all resistance measurements are corrected to a 20°C reference temperature using the equation specified in MIL-P-50884B, paragraph 4.7.4.1 (f). The resistance values in all cases shall not exceed 1.0 ohms.

6.7.1.7.2 The resistance values (after conversion to the 20°C reference temperature) of each conductor path on all patterns tested for continuity in this section (6.7.1) shall not exceed 1.0 ohms.

6.7.1.7.3 Record all data in accordance with the requirements specified on the applicable data sheet.

6.7.1.8 Results

The continuity tests were only performed on FPW, and therefore only on acrylic materials in this program. The thermal shock portion of these tests are discussed separately in paragraph 6.6.1.

6.7.1.8.1 Two Layer FPW

Resistance on all four measured samples after temperature conversions to 20°C at room ambient was 0.66 ohms, and ranged from 0.66 to 0.68 after the other three measurements following thermal shock, at the low temperature of -54 to -59°C, and at the high temperature of 71 to 76°, passing requirements easily.

6.7.1.8.2 Four Layer Test Pattern FPW

Resistance after temperature conversions to 20°C on all five measured samples ranged from 0.86 to 0.92 at all four measurements (at room ambient, after thermal shock, at the low temperature, and at the high temperature) passing requirements easily.

6.7.1.8.3 Multilayer Pilot Lot FPW

The two measured resistances on pattern D were 0.89 ohms, and all eight parts passed the requirement of resistance below 1.0 ohm maximum.

6.7.1.9 Conclusions: All acrylic FPW test parts passed all requirements for electrical continuity herein, in spite of through hole plating below inspection acceptance requirements on some test samples. However, the resistance values were close enough to the requirement (never less than half) so that further tightening of this requirement by lowering the permissible resistance does not seem practical at this time.

6.7.2 <u>Insulation Resistance</u>

6.7.2.1 Specification References

MIL-STD-50884B, paragraphs 3.10.2 (class 2) and 4.7.6 (class 2) for the multilayer pilot lot FPW. IPC-TM 650-2.5.9, except using test pattern B (of drawing SP 133-5040 for 2 layer FPW, and of drawing SP 133-5040 for 2 layer FPW, and of drawing SP 133-5047 for four layer FPW). MIL-STD-202, Method 302, paragraph 2.0. GDP TM 6-133-164 (paragraph 9), -168 (paragraph 9) and -174 (paragraph 11).

6.7.2.2 Test Equipment

As specified in IPC-TM 650-2.5.9, paragraph 4.0, for two layer and four layer FPW. As specified in MIL-STD-202E, Method 302, paragraph 2.0 for multilayer pilot lot FPW.

6.7.2.3 Applicability

Insulation resistance tests are applied only to the FPW, of which only those from acrylic materials are included in this program. Actually this test pattern is single layer, but the coverlay eliminates the surface moisture conductivity effects, so that it is really a test of resistance between lines encapsulated within the adhesive, as opposed to a test between layers, which might primarily test the polyimide resistance, such as the dielectric withstanding voltage test of the following section 6.7.3.

6.7.2.4 Sample Size

6.7.2.4.1 For Two Layer and Four Layer FPW

Five samples of test pattern B which were fabricated in accordance with Section 8 herein, were used for the following insulation resistance tests.

6.7.2.4.2 For Multilayer Pilot Lot FPW

Test pattern B from the two which are designated as -5 and -6, and test pattern E from all six basic test pattern assemblies of drawing SP 133-5067, which have been fabricated in accordance with Section 8 herein were used for the following insulation resistance tests.

6.7.2.5 Sample Preparation

6.7.2.5.1 Care was taken to remove the specified test patterns from the laminated assemblies without causing damage to the surrounding test patterns.

6.7.2.5.2 For two layer and four layer FPW, but not for the pilot lot, the edges would have been repaired (in accordance with GDP MPS 90.69E) if delamination had occurred during the cut-out process, and any such repair would have been recorded on the corresponding data sheet. No repairs were needed.

6.7.2.5.3 Prior to insulation resistance testing, two layer and four layer FPW samples were prepared in accordance with IPC - TM 650-2.5.9, paragraph 5.1.

6.7.2.5.4 For the pilot lot multilayer FPW, no special sample preparation was required for this test.

6.7.2.6 Method

6.7.2.6.1 For Two Layer and Four Layer FPW

6.7.2.6.1.1 Conditioning

All five test samples of each design were conditioned in accordance with IPC-TM 650-2.5.9, paragraph 5.2.1.

6.7.2.6.1.2 Test

During conditioning, tests were conducted in accordance with IPC TM 650-2.5.9, paragraph 5.2.2

6.7.2.6.1.3 After conditioning, tests were conducted in accordance with IPC-TM 650-2.5.9, paragraph 5.2.3, except that a potential of 500 VDC was used.

6.7.2.6.1.4 Measurements were taken in accordance with IPC-TM 650-2.5.9, paragraph 5.2.4, using the test pattern description in IPC-TM 650-5.8, test pattern "D" for terminal identification.

6.7.2.6.1.5 Electrification time was in accordance with IPC-TM 650-2.5.9 paragraph 5.2.5.

6.7.2.6.2 Method for Multilayer Pilot Lot FPW

The insulation resistance tests were divided into two separate test groups.

6.7.2.6.2.1 Test group 1 was test pattern "E" from all six SP 133-5067 samples.

6.7.2.6.2.2 Test group 2 was test pattern "B" from the two samples of SP 133-5067 identified as -5 and -6.

6.7.2.6.2.3 Both test group 1 and test group 2 were tested for insulation resistance in accordance with MIL-P-50884B, paragraph 4.7.6 (class 2).

6.7.2.7 Requirements

6.7.2.7.1 The insulation resistance between conductors shall not be less than 100 megohms when any samples are tested as specified.

6.7.2.7.2 Record all data in accordance with the requirements specified on the applicable data sheet.

6.7.2.8 Results

As applied only to FPW, and therefore only to FPW from acrylic materials in this program, the following insulation resistance results were obtained.

6.7.2.8.1 For Two Layer FPW

Compared to the minimum requirement of 100 megohms, the insulation resistance values between the four combinations of conductors on four samples of two layer FPW test pattern "B" ranged from 145 to 800 megohms, all passing.

6.7.2.8.2 For Four Layer FPW

Compared tc the minimum requirement of 100 megohms, the insulation resistance values between the four combinations of conductors on five samples of four layer FPW ranged from 160 to 1000 megohms, all passing.

6.7.2.8.3 For Multilayer Pilot Lot FPW

The insulation resistance on eight test pieces (2 of B pattern and 6 of E pattern) from six fabricated multilayer pilot lot FPW (SP 133-5067) all passed the minimum requirement of 100 megohms. Numerical values were neither requested nor recorded.

6.7.2.9 Conclusions

All FPW fabricated from polyimide - acrylic materials and tested herein passed the insulation resistance requirements of IPC-TM 650-2.5.9 and of MIL-STD-50884B, paragraphs 3.10.2 (class 2) and 4.7.6 (class 2), which indicates that the polyimide-acrylic materials are completely suitable for FPW fabrication insofar as insulation resistance is concerned.

6.7.3 Dielectric Withstanding Voltage

6.7.3.1 Specification References

MIL-P-50884B, paragraphs 3.7 and 4.7.3, except using test pattern "A" (of drawing SP 133-5040 for two layer FPW, drawing SP 133-5047 for four layer FPW, and drawing SP 133-5067 for multilayer pilot lot FPW). MIL-STD-202E, Method 301. GDP TM 6-133-164 (paragraph 10), -168 (paragraph 10), and -174 (paragraph 8). GDP MPS 90.69E.

6.7.3.2 Test Equipment

As specified in MIL-STD-202, Method 301, paragraph 2.0.

6.7.3.3 Applicability

The dielectric withstanding voltage test is applied herein only to FPW, and therefore only to acrylic materials in this program. It does require etched patterns on two or more layers, and becomes primarily a test of the polyimide, which is common to all of the FPW material systems in this program.

6.7.3.4 Sample Size

Test pattern "A" from five samples of the two layer FPW (drawing SP 133-5040), from five samples of the four layer FPW (drawing SP 133-5047), and from two samples of the multilayer pilot lot FPW (drawing SP 133-5067) identified as -1 and -2, was used in the following dielectric withstanding voltage tests, after fabrication in accordance with Section 8 herein.

6.7.3.5 Sample Preparation

6.7.3.5.1 Care was taken to remove the specified test patterns from the basic laminated test pattern assemblies prior to the start of testing, without causing damage to the surrounding test patterns.

6.7.3.5.2 The two layer and four layer test pattern FPW, but not the multilayer pilot lot FPW, would have been repaired if delamination had occurred during the cut out process, in accordance with GDP MPS-90.69E. Any such repair would have been noted on the corresponding data sheet, but none were needed.

6.7.3.6 Method

6.7.3.6.1 Two Layer and Four Layer MLF

All five samples of both the two layer FPW and the four layer FPW were tested in accordance with MIL-P-50884B, paragraph 4.7.3, complying, with the exceptions listed.

6.7.3.6.1.1 Magnitude of the test voltage was 500 VAC.

6.7.3.6.1.2 The current leakage did not exceed 5 ma.

6.7.3.6.2 For Multilayer Pilot Lot FPW

Pattern A of both samples of SP 133-5067 were subjected to the dielectric withstanding voltage test as specified in MIL-STD-202E, Method 301, paragraph 3.0, with the following conditions and exceptions.

6.7.3.6.2.1 Magnitude of test voltage was 500 VAC.

6.7.3.6.2.2 Duration of application of the test voltage was 30 seconds.

6.7.3.7 Requirements

6.7.3.7.1 The flexible printed wiring shall be examined for and shall have no flashover, sparkover, or breakdown during the application of 500 VAC for a minimum of 30 seconds.

6.7.3.7.2 During the dielectric withstanding voltage tests, the fault indicator shall be monitored for evidence of leakage current, which shall not exceed 5 ma.

6.7.3.7.3 Record all data in accordance with the requirements specified on the applicable data sheet.

6.7.3.8 Results

The dielectric withstanding voltage tests were applied only to FPW, and therefore only to acrylic adhesive materials in this program.

6.7.3.8.1 Two Layer FPW

Four acrylic FPW were tested, all passing easily with less than 1 ma. of current leakage compared to the 5 ma. maximum requirement, and with actual breakdown voltages of 2.0 to 3.0 KV as compared to the 0.5 KV minimum requirement.

6.7.3.8.2 Four Layer FPW

Five acrylic samples were tested, all passing readily with less than 1 ma. of current leakage compared to the 5 ma. maximum requirement, and with actual breakdown voltages of 2.5 to 3.0 KV as compared to the 0.5 KV minimum requirement.

6.7.3.8.3 Multilayer Pilot Lot FPW

Two pilot lot samples, as specified, were tested, both passing readily with less than 1 ma. of current leakage, compared to the 5 ma. maximum requirement. The specified pilot lot tests do not include increasing voltage above 500 VAC to breakdown.

6.7.3.9 Conclusions

All tested polyimide-acrylic FPW from this program passed the dielectric withstanding voltage tests of MIL-P-50884B, paragraph 3.7 and 4.7.3, and are suitable for FPW fabrication insofar as dielectric withstanding voltage requirements are concerned.

6.7.4 Dielectric Strength

6.7.4.1 Specification References

ASTM D-149 at 25°C, GDP TM 6-133-128, paragraphs 8 and 28.

6.7.4.2 Test Equipment

As specified in ASTM D-149.

6.7.4.3 Applicability

This test was planned for both the clad laminates (after copper is removed by etching) and the adhesive coated sheet, but not for the film adhesive or FPW. However, film adhesive was actually tested, and the results are included herein as paragraph 6.7.4.8.3. The coverlays rather than bondply were tested for a wider comparison since modified epoxy bondply was not among the test materials.

6.7.4.4 Sample Size

Five samples of each tested material were subjected to the following dielectric strength test. Samples were 4 inches square.

6.7.4.5 Sample Preparation

6.7.4.5.1 All samples being subjected to this test were etched in accordance with paragraph 8.1.1 herein prior to the measurement of sample thickness and the start of testing.

6.7.4.5.2 Sample Thickness

A minimum of three measurements per sample were taken and recorded on the applicable data sheet. The three measurements were then averaged and the result was recorded on the data sheet. The average thickness was used for the calculation of dielectric strength.

6.7.4.5.3 Except for etching of clad laminates, all samples were subjected to the dielectric strength test as received without any special preparation except for cutting to the specified size.

6.7.4.6 Method

All test samples were subjected to the dielectric strength test specified in ASTM D-149, with the following conditions and exceptions.

6.7.4.6.1 The short time tests for quick determination was used.

6.7.4.6.2 The voltage was increased from zero to breakdown at a uniform rate of 500 volts/second.

6.7.4.6.3 Test samples were conditioned at room ambient temperature for 24 hours minimum prior to testing.

6.7.4.6.4 Test samples were immersed in oil at a temperature of 25 $\pm$ 5^{o}C during testing. Oil type was as specified in ASTM D-149, paragraph 12.2.

6.7.4.6.5 Electrodes were one quarter inch in diameter.

6.7.4.6.6 Testing of all samples was performed using the same electrodes, and under the same environmental conditions.

6.7.4.7 Requirements

6.7.4.7.1 Criteria of Breakdown

The criteria of breakdown for these dielectric strength tests shall be in accordance with ASTM D-149, paragraph 7.

6.7.4.7.2 The dielectric strength minimum shall be 1800 volts/mil of thickness.

6.7.4.7.3 Record all data in accordance with the requirements specified on the applicable data sheet.

6.7.4.8 Results

6.7.4.8.1 On Copper Clad Laminate After Copper Is Removed By Etching

The averages of five samples each, relative to the requirement minimum of 1800 volts/mil, were 2960 for acrylic, 4810 for phenolic butyral, and 4550 for modified epoxy.

6.7.4.8.2 On Adhesive Coated Insulation Sheet

The average of five samples each, relative to the requirement minimum of 1800 volts/mil, were 4110 for acrylic, 3740 for phenolic butyral, and 4008 for modified epoxy.

6.7.4.8.3 Film Adhesive

These tests were added beyond the planned intentions, with averages of five samples showing dielectric strengths of 6630 for acrylic, 4860 for phenolic butyral, and 5490 for modified epoxy.

6.7.4.9 Conclusions

All test values were far above the requirements, so that dielectric strength is not a significant factor in selection among these three materials. Note that the first and third place positions alternated between the two types of materials (clad laminate and bondply) tested per plan, so that all three materials are essentially equivalent in this property. The film adhesive tests gave the best values, and in the same order as the coverlay (favoring acrylic). This test is still important in qualification specifications to prevent introduction of some inferior product in the future.

6.7.5 Dielectric Constant

6.7.5.1 Specification References

ASTM D-150 at 25°C and 1KHz. IPC-TM 650-2.5.5. GDP TM 6-133-128, paragraphs 9 and 29.

6.7.5.2 Test Equipment

As specified in ASTM D-150.

6.7.5.3 Applicability

This test is primarily another test of polyimide, which shouldn't vary significantly among these three material lines. It is applied to both the clad laminate (after copper is removed by etching) and to the adhesive coated insulation sheet, but not to the FPW in this program. The coverlay, but not the bondply, were tested herein. No electrical tests of film adhesive were included in this program plan or data sheets, but the three adhesive type were actually tested for dielectric constant, and that data is included below (paragraph 6.7.5.8.3).

6.7.5.4 Sample Size

Five samples of each material tested were subjected to the following dielectric constant test. Each test sample was 4 inches square.

6.7.5.5 Sample Preparation

6.7.5.5.1 Copper Clad Laminates

All copper clad laminate samples being subjected to this test were etched in accordance with paragraph 8.1.1 herein prior to the measurement of thickness and the start of testing.

6.7.5.5.2 Sample Thickness

A minimum of three measurements per sample were taken and recorded on the data sheet. The three measurements were then averaged and the result was recorded on the data sheet. The average thickness was then used for the calculations of dielectric constant.

6.7.5.5.3 All test samples were prepared in accordance with IPC-TM 650-2.5.5, paragraphs 5.1.2 and 5.1.3 prior to testing.

6.7.5.6 Method

All test samples were subjected to the dielectric constant test specified in IPC-TM 650-2.5.5, with the following conditions and exceptions.

6.7.5.6.1 A frequency of 1KHz was used.

6.7.5.6.2 Test temperature was 25 $\pm$ 5°C.

6.7.5.6.2 Tests were performed in air.

6.7.5.7 Requirements

6.7.5.7.1 The dielectric constant shall be 5.0 maximum.

6.7.5.7.2 Record all data in accordance with the requirements specified on applicable data sheets.

6.7.5.8 Results

6.7.5.8.1 Cu Clad Laminates

The dielectric constants, as measured by an independent testing laboratory, were 4.43 for acrylic, 4.05 for phenolic butyral, and 4.53 for modified epoxy clad laminates.

6.7.5.8.2 On Coverlay (Adhesive Coated Insulation Sheets)

The dielectric constants were 4.45 for acrylic, 3.57 for phenolic butyral, and 5.62 for modified epoxy coverlay materials.

6.7.5.8.3 On Film Adhesives

The dielectric constants were almost identical, at 3.49 for acrylic, 3.60 for phenolic butyral, and 3.50 for modified epoxy film adhesives.

6.7.5.9 Conclusions

All tested materials except the modified epoxy coverlay passed the requirement of a maximum of 5.0 for dielectric constant. All three types of adhesives, in the pure, uncured cast or film adhesive form, gave very good (3.5-3.6) and equivalent results, at or below the dielectric constants of the combined cured adhesive plus polyimide. Retesting for confirmation would be advisable before placing much significance on the failure of the modified epoxy coverlay.

6.7.6 Dissipation Factor

6.7.6.1 Specification References

ASTM D-150, IPC-TM 650-2.5.8, GDP TM 6-133-128, paragraphs 10 and 30.

6.7.6.2 Test Equipment

As specified in ASTM D-150.

6.7.6.3 Applicability

Dissipation factor tests were performed on the clad laminates after removal of copper by etching, on the coverlay for the adhesive coated insulation sheets, and on film adhesives (though the film adhesives were not included in the plans and data sheets), but not on any FPW assemblies.

6.7.6.4 Sample Size

Five samples of each material tested for dissipation factor were subjected to the following dissipation factor test. Each test sample was 4 inches square.

6.7.6.5 Sample Preparation

6.7.6.5.1 All clad laminate samples being subjected to this test were etched in accordance with paragraph 8.1.1 herein prior to the start of testing.

6.7.6.5.2 All test samples were prepared in accordance with IPC-TM 650-2.5.8, paragraphs 5.1.3 and 5.1.4.

6.7.6.6 Method

All test samples were subjected to the dissipation factor tests specified in IPC 2.5.8, with the following conditions and exceptions.

6.7.6.6.1 A frequency of 1 KHz was used.

6.7.6.6.2 Test temperature was $25 \pm 5^{\circ}C$.

6.7.6.6.3 Tests were performed in air.

6.7.6.7 Requirements

6.7.6.7.1 The dissipation factor shall be 0.250 maximum.

6.7.6.7.2 Record all data in accordance with the requirement specified on the applicable data sheets.

6.7.6.8 Results

6.7.6.8.1 On Clad Laminates After Copper Removal by Etching

The average dissipation factors obtained from five samples of each material were all well below the requirement of 0.250 maximum, at 0.054 for acrylic, 0.025 for phenolic butyral, and 0.088 for modified epoxy from clad laminates after etching.

6.7.6.8.2 On Coverlay (Adhesive Bonded Insulation Sheets)

The average dissipation factors obtained from five samples of each material were all well below the requirement of 0.250 maximum, at 0.071 for acrylic, 0.006 for phenolic butyral, and 0.082 for modified epoxy coverlay materials.

6.7.6.8.3 On Film Adhesive

Though not included in the plan or data sheets, the average dissipation factors obtained from five samples of each film adhesive were 0.002 for acrylic, 0.003 for phenolic butyral, and 0.002 for modified epoxy, all of which average a hundred fold below the requirement maximum of 0.250.

6.7.6.9 Conclusions

All materials tested herein show dissipation factors far below requirements and this property should not be a significant factor in the material selection among these three, though still a valuable test for screening future applicant materials.

6.7.7 Volume Resistivity

6.7.7.1 Specification References

ASTM D-257. GDP TM 6-133-128, paragraphs 11 and 31.

6.7.7.2 Test Equipment

As specified in ASTM D-257.

6.7.7.3 Applicability

Volume resistivity was tested in this program on the same materials tested for dielectric strengths, dielectric constant, and dissipation factor. These are clad laminates after copper is removed by etching, coverlay as a representative adhesive coated insulation sheet, and the (unscheduled) film adhesive. Volume resistivity was not included in the tests of FPW samples.

6.7.7.4 Sample Size

Five samples of each material being tested for volume resistivity were subjected to the following test. Each sample was four inches square.

6.7.7.5 Sample Preparation

6.7.7.5.1 Clad Laminates

All clad laminates being subjected to this test were etched in accordance with paragraph 8.1.1 herein prior to measuring sample thickness and the start of testing.

6.7.7.5.2 Sample Thickness

A minimum of three measurements per sample were taken and recorded on the applicable data sheet. The three measurements were then averaged, and the result was recorded on the data sheet. The average thickness was then used for the calculation of volume resistivity.

6.7.7.5.3 Electrodes

Electrodes for this test were painted on in accordance with ASTM D-257, paragraph 6.1.3. The diameter of the electrodes was 1.02 ± .030 inch.

6.7.7.6 Method

All test samples were subjected to the volume resistivity test specified in ASTM D-257 with the following conditions and exceptions.

6.7.7.6.1 A test temperature of 200°C was used.

6.7.7.6.2 The method of measurement was via microsectioning.

6.7.7.6.3 The reported values were steady state.

6.7.7.7 Requirements

6.7.7.7.1 The volume resistivity minimum shall be 1×10^{10} ohms/centimeter.

6.7.7.7.2 Record all data in accordance with the requirements specified on the applicable data sheets.

6.7.7.8 Results

6.7.7.8.1 On Clad Laminates After Copper Removal by Etching

All three tested laminate materials easily surpassed the minimum requirement of 1×10^{10} ohms/cm., with 4.3×10^{11} for acrylic, 1.8×10^{12} for phenolic butyral, and 2.2×10^{11} for modified epoxy clad laminate after etching.

6.7.7.8.2 On Coverlay (Adhesive Coated Insulation Sheet)

All three tested coverlay materials easily surpassed the minimum requirement of 1×10^{10} ohms/cm., with 2.7×10^{12} for acrylic, 1.3×10^{13} for phenolic butyral, and 2.6×10^{12} for modified epoxy coverlay.

6.7.7.8.3 On Film Adhesive

All three tested film adhesives easily surpassed the minimum with 5.7×10^{13} for acrylic, 9.5×10^{12} for phenolic butyral, and 5.0×10^{13} for modified epoxy film adhesives.

6.7.7.9 Conclusions

Since all tested materials easily surpassed the volume resistivity requirements of ASTM D-257, and the comparison order was opposite for the adhesive film versus the clad laminate and coverlay, this test should not be significant in the selection among these three materials, though it should remain as a qualification requirement for future material applicants.

6.8 TEST SUMMARY

6.8.1 Material Testing Summary

6.8.1.1 The materials test program was completed as outlined in Tables II, III, and IV of this program's "Test and Evaluation Plan", CDRL A002, Code Ident. 99584, M-24-S-476, October 1975 which is reference 7 herein. Material test results have been summarized. The electrical parameters, which are primarily a function of the polyimide dielectric insulation material, were generally adequate in all three materials. The dielectric strength, dielectric constant, dissipation factor, volume resistivity and tensile strength of the dielectric materials were satisfactory for all materials tested. Differences in polyimide and adhesive thickness among the vendor products had more effect than the basic material differences, and the tests have primarily confirmed that none of the tested materials would be disqualified on the basis of these tests.

6.8.1.2 The largest quantity of materials tests involved the peel strength tests. However, since the peel strength tests after high temperature exposure failed the initial estimated upper criteria limit for all materials tested, a set of copper clad laminate materials representing all three adhesive types (acrylic, phenolic with epoxy primer, and modified epoxy) were tested under modified high temperature exposure conditions of 350°F instead of 400°F, but for the same time period of 24 hours. The 350°F samples also differed as unetched (Method A) samples, whereas the original tests at 400°F were on etched, narrow strips (Method C). The resulting peel strengths after exposure at 350°F were 4.0 for acrylic, 3.8 for phenolic butyral, and 6.5 for modified epoxy. Data from this single test is too limited for dependable conclusions, but this appears to be an area deserving further study, especially as future needs further increase either maximum exposure temperatures or the exposure time at temperature for some FPW parts.

6.8.1.3 The averages of all the available peel strength data were summarized. Repeating the overall averages, acrylic gave 7.1 versus 4.6 for phenolic butyral and 3.8 for modified epoxy. After solder immersion, averages were 5.8 for acrylic versus 2.7 for phenolic butyral. "Copper Bond Strength Method A" was completed on both acrylic and phenolic butyral clad materials without failure, although the strengths on acrylic were 50% higher. Moisture absorption tests were completed without failures on either acrylic or phenolic butyral clad laminates. In "Initial Tear Strength" tests on clad materials, only the acrylic passed the requirements of 400 pounds per inch of total thickness, and "Propagate Tear Strength" tests were cancelled as not applicable to flexible materials. "Folding Endurance" tests, after second folding, showed an 80% success rate on acrylic, and 60% on phenolic butyral clad laminates. On adhesive-coated insulation sheets, the success rate was 100% on acrylic and 90% on phenolic butyral (polyimide split through on one sample of ten). Curl resistance tests were cancelled since that is no longer a problem with these materials. The copper clad acrylic and modified epoxy laminates are delivered in flat sheets rather than in rolls, and the coverlay and bondply flatten promptly after cutting. Even the prior materials (phenolic butyral plus epoxy) have eliminated their earlier curling problems, by changes of their release materials. Other major conclusions from the materials testing (beyond the peel test strength) are that the acrylic also provides significant improvements in folding endurance and flexural fatigue compared to the materials presently being used.

6.8.1.4 Adhesive Flow Tests

A series of "Adhesive Flow Tests", with special artwork (SP 133-5055) and a template for drill and cut-out of adhesive, were added to the original test plan to determine whether an important problem of excessive adhesive flow (encountered with the phenolic butyral plus epoxy adhesive system) would be aggravated or resolved. Whereas greater flow might eliminate a potential adhesive material by causing prohibitive rework costs, reduced flow will provide additional labor cost savings in production by minimizing manual rework problems encountered with present materials when small bonding pads are associated with thick copper layers. The five samples each of both cast and coverlay materials, with both acrylic and phenolic butyral adhesives, were completed and tested, showing considerably less flow for the acrylic materials, with the corresponding promise of further cost savings with acrylic adhesives, again due to reduced scrap and rework in production. Additional fabrication and testing were added to the program (without increasing funding) to determine the process variable effects of reduced lamination pressure and of attempted reflow laminations. The results indicate that this problem (excessive flow on some harness configurations, requiring appreciable rework) would be resolved by use of acrylic adhesives.

6.8.1.5 The summarized results of the material tests other than peel strength in the Test and Evaluation Plan (Reference 7) are as follows:

TABLE XV: Summary of Material Tests Except Peel Strength

Test Description	Results on Acrylic Materials	Results on Other Materials
1. Dielectric Strength	Good	Good
2. Dielectric Constant	Good	One Fails
3. Dissipation Factor	Good	Good
4. Volume Resistivity	Good	Good
5. Tensile Strength	Good	Good
6. Fungus Resistance	Vendor Requirement cancelled.	
7. Copper Foil Elongation	Good	Good
8. Copper Bond Strength As Received Method B	Good	Both Failed
9. Copper Bond Strength As Received Method A	Best	Good
10. Moisture Absorption	Good	Good
11. Dimensional Stability After Etch	Good	Good
12. Above plus Thermal Exposure	Good	Good
13. Dimensional Stability After Thermal Exposure	Fair	Fair
14. Folding Endurance (clad)	80% Pass	60% Pass
15. Folding Endurance (insulation)	100% Pass	90% Pass
16. Copper Foil	Good	Good
17. Tear Strength, Initial	Good	Good
18. Flexural Fatigue	Good	Less on Present Material
19. Curl Resistance	Good	Good
20. Tear Strength, Propagate	Cancelled as not applicable to FPW	

6.8.2 Two Layer FPW Test Summary

Tests on two layer FPW confirm earlier materials test conclusions in general, although there are significant reductions in flexural fatigue life due to lower flexibility of electroplated copper as compared to rolled annealed copper of vendor laminates.

6.8.3 Four Layer FPW Test Summary

Test results on four layer FPW indicated that smear removal and copper plating were quite successful. Some resist breakdown was observed in several large holes, of diameters beyond those normally used for interconnections as plated through holes in General Dynamics flex harness designs. This warning signal of a problem's proximity is believed independent of the flex harness adhesive material, however, depending more upon the photoresist, plating, touchup, etching, and design. The multilayer test results also repeated previous material test indications of acrylic benefits.

6.8.4 Pilot Lot Testing Summary

All testing has been completed, confirming the producibility of both two-layer and multilayer flexible printed wiring test patterns, and the multilayer Pilot Lot (an SM-2 production multilayer flex harness, plus test patterns) with excellent results on peel strength of etched circuit lines, and with no failures on electrical continuity tests of the six tested parts. The results of enhanced peel strength and resistance to thermal shock were consistent with the values obtained for the important original material test parameters. This also confirms the success of the process development for acrylic material fabrication, including the critical lamination and smear removal fabrication processes. Some tests, such as folding endurance and flexural fatigue, show failures or lower values on the thicker, plated, flex harnesses than on the thinner laminates with only annealed copper or insulation materials. Good results were obtained on all Pilot lot tests, with everything passing except for one coverlay flaw resulting from a non-standard operation related to tooling, and some thin copper plating which would have been corrected in normal Production by simply adding more electroplated copper. This has elevated the confidence level to the point of unqualified recommendation for change of material by this project team to key factory management and technical personnel.

TABLE XVI Results on Pilot Lot

Visual Exam	All pass except for a flaw in coverlay on one part, from a non-standard procedure (used to correct an error in trimming coverlay before laminations) not related to materials.
Electrical Continuity Tests	All Pass 100%
Peel Strength on Etched Strips	12 lbs/inch (Very Good)
Dielectric Withstanding Voltage	All Pass
Thermal Shock	All Pass
Insulation Resistance	All Pass
Moisture Resistance	All Pass
Terminal Area Bond Strength	All Pass
Conductor Plating Thickness	Two failed, but these would simply be returned for additional plating after in-process measurement in normal Production, and the failures are not related to materials.
Solderability	All Pass

7.0 PROCESS DEVELOPMENT

7.1 INTRODUCTION FOR PROCESS DEVELOPMENT

7.1.1 Requirements

Fabrication process development had to solve all of the requirements for a practical production process to use acrylic-based adhesives for polyimide type flexible printed circuitry. Preliminary process studies revealed the major differences in satisfactory processing between the single-adhesive modified acrylic and the current materials system which used epoxy primers with phenolic butyral adhesives.

7.1.2 Testing of Present Flexible Printed Wiring Processes

Test panels were processed through the present production processes for double and multilayer FPW. The fabrication of preliminary development samples indicated that the cleaning, drying, photoresist application (two different resists), photo exposure, photo developing, and copper etching (with either chrome-sulfuric or ferric chloride etchants) all produced acceptable results with current Production processing methods. The "print and etch" operations required for making peel test panels were successful. Two layer through hole plating also was adequate with current production techniques. Drilling results were as good and probably somewhat better with the acrylic adhesive materials than with the materials in current Production use. These drilling results were obtained on the basis of limited data from microscopic examination of drilled holes (observed at an angle with back lighting) and on mounted cross sections of plated holes.

7.1.3 Remaining Problems

The problems which appeared are listed below:

7.1.3.1 Differences in suitable resist stripper selection to avoid loss of circuitry bond strength.

7.1.3.2 Lamination requirement differences in pressure, temperature, and preparation.

7.1.3.3 Substantial differences in safe processing chemicals for use in cleaning and plating operations.

7.1.3.4 Lack of a satisfactory smear removal and through hole plating process for acrylic adhesive laminates in the current industry state-of-the-art. This had been by-passed with some success by some within the industry by extreme care and skill in drilling operations, and/or by physical hole preparation methods such as liquid honing. These can produce multilayers which successfully pass adequate testing, but still lack adequate proof of continuing producibility. Therefore a successful chemical smear removal and plating cycle was vigorously sought as a principal function of this project. The other differences, while deserving further optimization, were within practical solution range for this project. The initial development work was done on a small scale in test tubes, and involved literally thousands of individual chemical immersion operations.

7.1.4 Development of pilot plant facilities for nine by twelve inch flex harness panels had to be accomplished for fabrication of the various preliminary multilayer test patterns. This test pattern size was adequate for proofing of the basic processes during this development period.

7.1.5 Development of fabrication capability mainly in Production facilities (with minor modifications as needed) was planned to evaluate handling of hardware in a production mode. A fabrication process had to be defined and documented describing the production of parts, and updated per the continuing refinements thereof, throughout the program to the pilot lot fabrication.

7.2 DEVELOPMENT FOR MATERIALS EVALUATION TESTS

Only a few process developments were necessary for the material evaluation tests, as follows:

7.2.1 Print and Etch

Confirmation that the standard practices were adequate for print and etch operations was accomplished easily.

7.2.2 Stripping of Photoresist

AC-10 photoresist stripper which was used in the printed wiring production area reduced the peel strength of the etched circuitry of the first group of test panels enough to permit some lifting of narrow lines during processing. After preliminary failures of lifted circuitry and obviously reduced peel strength on etched circuitry after stripping of resist, other test panels (after print and etch) have been stripped in various proprietary strippers. While some other failures were observed, presumably due to excessive reactions with organic solvent constituents of those strippers, several adequate strippers were identified through vendor recommendations and tested here on etched acrylic-adhesive panels. DuPont's 1100X, Shipley's 1123 Stripper, Dynachem's Alkastrip 99A, and London Chemical's Loncostrip ARS-3 each stripped photoresist without visible damage. Peel tests before and after stripping in DuPont 1100X and coating with immersion tin differed by less than the 20% which has been allowed in our test plan for the IPC solvent exposure peel tests. Avoidance of excessive stripping time will probably be a process requirement. The conclusions are that each stripper considered for acrylic materials needs testing for its effect on thin-line etched circuitry adhesion, as well as for its other properties of resist-stripping efficiency, costs, safety, etc., but that there are a variety of strippers commercially available which are quite practical for acrylic adhesive laminates. Stripping resist from acrylic FPW is therefore no particular problem, except that this experience does re-emphasize the importance of checking each new process chemical for each product to be used therein.

7.2.3 Laminations

It was also necessary to laminate coverlay, bondply, and film adhesive to untreated copper, epoxyglass, and untreated polyimide for the materials peel strength tests. The basic lamination parameters were available from the vendors. Since these tests specified use of vendor-recommended laminating parameters, rather than developed improvements, and since even the bondply is on the surface rather than between clad laminates as for multilayers, these laminations were completed without any major problems. However, acrylic adhesive flow tests were checked at both 200 psi and 400 psi in this program, and the lower pressure (200 psi) combined with year old acrylic materials, did show insufficient flow to fill sharp fillets thoroughly, whereas those at 400 psi yielded excellent results without excessive adhesive flow.

7.3 PROCESS DEVELOPMENT FOR TWO LAYER FLEXIBLE PRINTED WIRING

7.3.1 Introduction for Two Layer Development

No "T- joints" are required for two layer FPW, and the through hole plating merely has to cover the non-metallic areas thoroughly (without voids or excessive nodules), so that extensive "smear removal" is not essential. The added steps (beyond those for material tests) which are involved here are drilling, electroless plating, electroplating, cleaning and baking for lamination, lamination of coverlay, and immersion tin plating or related coatings. All of these except the coverlay lamination were adequate when first checked with currently standard processing methods. While drilling results still deserve improvement, they were comparable to those with present materials, much better than those common two years ago, and quite adequate for passing modern test requirements. The following paragraphs list the additional process development needed to fabricate the two-layer, plated-through-hole test patterns that were used to evaluate the processes that had been developed for acrylic adhesive materials up to that point in this program. Five test patterns were fabricated using an acrylic-adhesive, copper-clad laminate that has 1 ounce copper on both sides of a 2 mil thick polyimide base dielectric. The first two layer FPW had already been fabricated and delivered for primary tests prior to design of the coverlay. A coverlay consisting of 1 mil thick polyimide insulation sheet coated with acrylic adhesive on one side was laminated to both sides of the test pattern on four samples to complete the five samples requirement, but in order to avoid a difference in test samples, only the last four were tested in accordance with the formal program herein.

7.3.2 Coverlay Lamination Development

The first coverlay lamination needed for this program was done without any preliminary preparation of the coverlay material (acrylic adhesive on one side of polyimide). The same lamination parameters developed for the multilayer (bondply) lamination were used for standardization advantages. As predicted, the vacuum prebake previously developed herein for bondply was not needed, presumably because the polyimide is on the outside where moisture can escape readily without trapped gases causing blisters. Since two thirds of the adhesive sheets in the standard four layer multilayer FPW with covercoats, and all of the adhesive used for two layer FPW (covercoats only), are coverlay which will therefore not require a drying operation before lamination, this greatly reduces the vacuum drying requirements for Production. This completed the lamination development needed for this program, with no known remaining lamination problems. Coverlay lamination was quite successful on two layer FPW, except that results were improved by a

7.3.2 Coverlay Lamination Development (Cont'd)

few modifications from prior standard procedures and/or preliminary lamination parameters (based on the lower-processing-cost side of vendor recommended operating ranges) as follows.

7.3.2.1 Pressure Pads

The number of one sixteenth inch thick fiberglass-reinforced silicone rubber lamination pressure distribution pads used per stack was increased from three sheets to four sheets.

7.3.2.2 The lamination time at the lamination temperature (not including heating and cooling times) was first tried at twenty minutes, then increased to forty minutes.

7.3.2.3 Lamination Temperature

The lamination temperature was increased from 350°F to 390°F, which improved results. It was later reduced partially to 380°F, which still seemed to give excellent results, with a slight decrease in heating time. This is still not necessarily optimized, but is adequate for the scope of this program of preliminary development for introduction of a new material and process.

7.3.2.4 Lamination Pressure

The lamination pressure was increased, from the early trials at 300 psi (midway in vendor recommendations) to 400 psi (the top of the range recommended by vendor).

7.4 PROCESS DEVELOPMENT FOR MULTILAYER FLEXIBLE PRINTED WIRING

7.4.1 Requirements

To evaluate four layer, plated through hole test patterns that have been fabricated using the processes that have been developed for acrylic adhesive materials up to this point in the program, five test patterns were fabricated using two (2) acrylic adhesive copper-clad laminates that have 1 ounce copper on both sides of a 2 mil thick polyimide base dielectric. These were laminated together using bondply that has acrylic adhesive on both sides of 1 mil thick polyimide insulation sheet. A coverlay consisting of 1 mil thick polyimide insulation sheet coated with acrylic adhesive on one side was laminated to both sides of the test pattern. This evaluation could

7.4.1 Requirements (Cont'd)

be repeated if test results indicated the need for further process development. A test pattern, SP 133-5047, was prepared to incorporate the standard IPC test patterns with a minor addition for in-process coupons. This included photographic tools and drilling tapes.

7.4.2 Major Problems

Paragraph 9.1 herein lists the operations for multilayer FPW. These require "T-joints" in the plated through holes, so that exceptional drilling results and/or efficient physical and/or chemical smear removal is essential. Most of the multilayer operations are repetitions of the previous two layer processes, except that the substrate is not as flat for photoetching and for coverlay lamination, and obviously multilayers are less flexible (which simplifies handling). The X-ray after drilling is an optional operation, simply to confirm alignment and increase inspection insurance. Therefore the real multilayer challenge for acrylic materials is the smear removal for plated through holes. Information available at the start of this program indicates that the present state-of-the-art did not include a satisfactory chemical smear removal and through hole plating sequence, but that some satisfactory plated through holes in multilayers had been obtained by specialized drilling and/or physical smear removal methods such as liquid honing or ultrasonic slurry cleaning. The major process development effort of this program was required on the smear removal and plating sequence for multilayers.

7.4.3 Requirements For Plated Through Holes

7.4.3.1 Plating Adhesion

Fortunately, the test requirements for rejection of plated through holes are not too complicated. Adequate plating adhesion was checked by angular cuts with an X-acto knife, followed by bending and microscopic examination. The requirement is that no obvious separation between copper layers shall be visible under 10X magnification of the plating interface after cuts with an X-acto blade, band saw, or shear. A simple documented test is that the cut edge of the mounted hole cross-section coupon should not be separated at the plating interface. The interface and electroless plating are normally visible as a darker line, which is no cause for rejection. For more development information, more extreme tests were provided by higher magnification, angled cuts, and bending parallel to the cut.

7.4.3.2 Observations Within Holes

Results of drilling and of individual smear removal and plating process operations, plus plating voids and acrylic exuding from between the layers in plated through holes, were observed by microsopic observation inside the holes, with back-lighting and observation at an angle.

7.4.3.3 Acceptability Criteria

IPC-A-600A Section II documents acceptability criteria which are used in this study for flexible printed wiring. This includes Section 1 for through hole plating, Section 3 for plating, Section 5 for etching, Section 6 for conductors, Section 7 for fabrication, Section 8 for eyeletting (not involved in this study) and Section 14 for miscellaneous terms and definitions. Blisters and wrinkles after lamination can usually be easily detected visually. IPC-A-600A Section 4 documents the acceptability criteria for lamination. Blistering and delamination shall be cause for rejection, but most of the other terms are not applicable in the absence of fiberglass. Some discoloration and haloing due to variations in copper oxide surface treatments or chemical undercut effects, which do not cause delaminations visible in cross-sections of similar appearance at 30X, shall not in themselves be cause for rejection. This will be reconsidered and modified when and if such appearances are significantly related to some reduction in reliability. Section 12 of IPC-A-600A covers multilayer printed wiring "boards", but it shall also be applied to the "flexible" multilayer printed wiring in this study, except that for FPW, the maximum misregistration shall be such that the drilled hole may be tangential to but does not extend beyond the annular ring at any point of any pad on any internal layer. In other words, the two circles (holes and pad) may touch in X-rays after drilling of multilayers. On the external layers, the eccentricity of a hole to its surrounding conductor shall leave at least .005 inch of pad remaining around the periphery of the hole.

7.4.3.4 Development Control

All of these in-process tests were performed by the process development chemist during development. For more detailed information, microscopic examination of cross sections of plated through holes were used, as needed, on selected development and test samples. Small samples of drilled multilayer panels were processed in small laboratory process lines. The temperatures, the concentrations of each of the constituents in each solution, the processing sequence, the nature of each solution, the time of immersion in each solution, the time, nature, and quality of each rinse operation, any drying or baking operations, permissible holding periods and solutions, agitation conditions and spray conditions, and numerous other variables affect the success of the overall plated

7.4.3.4 Development Control (Cont'd)

through hole process on a multilayer laminate with copper, copper oxide surface treatment, polyimide, and acrylic interfaces.

7.4.3.5 Development Recycling

The selected process parameters and the tests of the resultant products appear in this final report. The fabricate, test, evaluate, and recycle process for the smear removal, plating, lamination, drilling, and photoetching were recycled through additional process development, fabrication, test, and evaluation cycles as frequently as required in the search for a practical process within the time frame and other limitations of this program.

7.4.3.6 Preliminary Efforts

Plated through holes of acrylic adhesive multilayers, processed through the present production flexible printed wiring smear removal and electroless plating sequence, were rejected for plating voids, excessive exudation of the acrylic adhesive within the holes, and poor adhesion of plating to bare copper. These processing problems as noted above were observed on preparing samples of the acrylic material system through the process presently employed for the epoxy-phenolic butyral material system. These results then served as a guide for the process development required to optimize the acrylic system.

7.4.3.7 Progress in Wet Chemical Smear Removal

7.4.3.7.1 Smear Removal In Drilled Holes Prior to Plating: The smear removal process used for phenolic butyral and epoxy adhesive materials is completely unsatisfactory for these acrylic materials. There is a softening of the acrylic followed by swelling and exudation between layers, with resulting voids and adhesion failures. Obviously special procedures are essential to avoid or remove smear in acrylic multilayer plated through holes. After a preliminary survey of the industry state-of-the-art, a series of chemical tests were made on coupons with drilled holes and exposed surfaces of copper, polyimide and acrylic, in search for a reasonably practical etchant system. Safety considerations and equipment limitations somewhat restrict the range of feasibility in the laboratory for potential etchants. These three materials (copper, polyimide and acrylic) resisted several hours immersion in hot, concentrated sulfuric acid. Ultrasonic cleaning in an aqueous solution of methyl ethyl ketone (MEK) and chlorothene in a slurry of Ajax cleanser removed some drill debris but caused swelling of acrylic into drilled holes. Concentrated phosphoric acid both at room and boiling temperature proved inadequate.

7.4.3.7.1 Smear Removal In Drilled Holes Prior to Plating (Cont'd)
Some alkaline organic proprietary solutions generated more swelling than etching. Unsuccessful results were obtained with concentrated acetic acid, hydrochloric acid, alcoholic potassium hydroxide, butanol, cellosolve, methylene chloride, etc. Some oxidizing chemicals such as concentrated nitric acid are impractical because of excessive etching of the copper. Most chemicals strong enough to dissolve acrylic are likely to diffuse deeply enough to weaken the peel strength between acrylic and either the copper or the polyimide, instead of cleanly etching the surface. Solutions which softened the acrylic surface excessively (by hydrolyzing part of the acrylic) led to undesirable swelling and exudation in the plating sequences. A laboratory line was set up with heating and rinsing facilities. Using laboratory chemical supplies, concentrations were controlled by fresh makeup of solutions rather than by chemical analysis. Special test panels with exposed flat surfaces of copper, polyimide, and cured acrylic adhesives were prepared by etching copper from part of one side of double clad laminate, etching the acrylic from that side, and finally etching the copper from part of the other side to expose a fresh acrylic surface. These panels were used for preliminary development of smear removal and plating processes. When processing cycles were adequate for exposed flat surfaces, the somewhat different effects on the internal multilayer hole surfaces were studied. Multilayer test panels were fabricated and holes were drilled as a series of SP 133-4017 panels. Small test coupons were observed in process after most steps by microscopic examination with back lighting and angular observation. Photomicrographic cross sections of plated through holes were made to compare results from the various smear removal process modifications on both double clad and multilayer flex harnesses, and were observed after plating for finer definition of results. Continuous observation and evaluation during processing, and repeated recycling with changes of conditions based on prior test results, were used extensively. In order to evaluate the results, technical judgment was necessary to fill the voids in experimental data. The original laboratory lines involved as many as thirty solutions in sequence, with a multitude of rinses, to overpower the problems with superlative decontamination. After successful processing of samples, the line was gradually shortened to distinguish between essential and optional operations, to make it more practical. In spite of their obvious hazards of waste control for EPA and contamination control for plating, chromic acid etchants were still selected as the best available within the scope of this study. Microscopic observation of both plated and unplated drilled holes at various stages of the plating sequence, with backlighted, angular observation, sometimes aided by immersion tin coatings for better visibility, and sometimes by mounted cross sections, were used for judging results. Substantial differences in effects on planar surfaces

7.4.3.7.1 Smear Removal In Drilled Holes Prior to Plating (Cont'd)
versus sheared edges versus drilled holes were observed, and required consideration in all evaluations.

7.4.3.7.2 Smear Removal Etchant

Finding a true "etchant" which removes acrylic material, leaving a reasonably clean surface instead of simply softening the surface, is the first problem in smear removal. For the chromic acid system which was selected for wet chemical smear removal in this program, avoiding chromium poisoning of the electroless line was the major problem. Both of these problems were investigated, as outlined below.

7.4.3.7.3 Chromic Acid Etchants and Controls

Series of tests compared the effects of numerous variables with chromic acid on cured acrylic and polyimide surfaces. These variables included: 1). Temperature, 2). Chromic acid concentration, 3). Various acid additives, 4). Various salt additives, 5). Concentration of additive, and 6). Effect of usage, or buildup of etch products, on etch rate and contamination. A suitable means of interpreting the results in-process was sought, and a means of judging the etchant quality to avoid excessive analytical costs for quality control was needed. These objectives were achieved. The details of the evaluation and control methods which were devised are described in Appendix I attached hereto. Etching of polyimide may not have to be appreciable for this purpose, since the typical smears are from the adhesive or from the drill entry or backup materials, frequently from overheated plastic materials. The high temperature strength and thermal resistance of polyimide protect it from these ordinary "smear" hazards. Therefore adequate smear removal of flex harness holes does not seem to require etching of the polyimide, on the basis of cross sections observed to date here, and according to verbal industry communications. Therefore the strong alkaline preliminary softening hydrolysis of polyimide by "Isoprep 177" is not necessary for acrylic multilayer FPW smear removal. Its use seems undesirable for this project at present, because it also attacks and softens the acrylic adhesive, leading to later problems.

7.4.3.7.4 Electroless Copper Line Development to Solve Chromium Poisoning Problems

Appendix II provides details of the chromium poisoning problem which has plagued the electroless copper lines of plating establishments for decades as "intermittent" problems of voids in plated through holes and adhesion failures between base copper and copper plating over electroless copper. This problem becomes extreme in the plating of acrylics after chromic acid smear removal. Its resolution was essential to permit satisfactory plating of multilayer plated through holes in acrylic laminates after chromic acid smear removal.

7.4.3.7.4 Electroless Copper Line Development to Solve Chromium Poisoning Problems (Cont'd)

Appendix II also outlines the development of electroless plating line modifications (as a major part of the acrylic flex harness study) which have produced several acrylic multilayer test coupons, without any of the plating voids and adhesion problems normally associated with chromium poisoning. Some additional details are included in Appendix III, and an example of an FPW through hole plated after the chromic-phosphoric acid smear removal and electroless copper plating developed in this program is shown in Figure 7-1.

7.4.3.7.5 Presentation on Smear Removal and Copper Plating of Through Holes

A presentation based on the findings reported herein was made at NEPCON 76 West, the National Electronic Packaging Conference at Anaheim, California, which included successful results on wet chemical chromic acid smear removal and electroless copper plating of acrylic-adhesive, polyimide laminates for multilayer flex harnesses. A similar talk was presented at the New York "NEPCON 76 East" in June. Inquiries for additional information, including interim reports of this contract, requested by referral through the NAVPRO liaison office, were received and honored from personnel from Lockheed at Sunnyvale, Burroughs at Carlsbad, Boeing at Seattle, Tektronics in Oregon, and DuPont at Saugus and Wilmington. Process development of a wet chemical smear removal process suitable for MLF with acrylic adhesives appears successfully completed through the laboratory stage, insofar as is revealed by photomicrographic cross section of the plated through holes. Additional fabrication, test, and evaluation is required for confirmation of process on a product line scale. Charts shown in Appendix II compare the old process for phenolic butyral plus epoxy adhesives with the new process for acrylic adhesives, when each was at the same stage of advanced technology development for a maximum yield, base line process prior to modifications for production compatibility. The acrylic processing line is substantially shorter. Much of the reduction is in the complex rinsing requirements previously needed to avoid chromium poisoning of the electroless copper line. The overall results should be mainly yield improvement rather than substantial labor saving.

7.4.3.7.6 Production Use of the Wet Chemical Smear Removal Process for Acrylic FPW

From a complete smear removal and electroless plating cycle typical for multilayer printed wiring boards and flex harnesses, this program's development can delete a total of five solutions (hot water, soldium bisulfite, hydrochloric acid preceding persulfate, ammonium persulfate, and sulfuric acid), plus five rinsing sequences, and all of the facilities, chemicals, control, labor, and processing time associated with these ten or more steps, while improving results.

7.4.3.7.6 Production Use of the Wet Chemical Smear Removal Process for Acrylic FPW (Cont'd)

The process development work was expanded to include a complex flex-rigid laminate from the Lockheed Missile and Space Division, which they have been experimenting with in support of their Trident program.

This contact was made as a result of a presentation made at the NEPCON West symposium by S. A. Hays of General Dynamics, describing the chromic acid smear removal process developed for acrylic adhesive polyimide laminates. This is the principal problem area encountered by the Lockheed people. By coordinating through the Navy technical monitor at Pomona, recommendations for significant improvements of lamination and chemical smear removal were provided to Lockheed personnel, and samples of their material system are being subjected to our processing. Samples provided by the Lockheed Company were plated at General Dynamics to prove that the process developed in this CONRAD can also resolve their problem. Figure 7-2 shows satisfactory wet chemical smear removal and plating on a flex-rigid hybrid hole wall over the acrylic, polyimide, and copper interfaces. Application of these simplifications in the chromic acid smear removal and electroless copper plating lines to general Production use for all multilayer flexible and rigid printed wiring (harnesses, hybrids, and boards) is beyond the scope of this study, and would require further confirmation studies by Advanced Manufacturing Technology. However, this study has provided the initial development which provides the potential for substantial reductions in the processing line length, processing time and labor costs, chemicals and heating costs, rinse water requirements, ammonium and persulfate complications of the water recycling process, and plating scrap and rework losses of both flexible and rigid printed wiring products. Though this "wet" process provided excellent results on acrylic FPW, it is still not as simple and cost effective as the "dry plasma smear removal" (patent applied for) process (see next paragraph) which was developed here at General Dynamics, Pomona Division, in a complementary IRAD (Internal Research and Development) program, and which will be used here at GDP for Production. This offers even greater simplification of smear removal for acrylic plated through holes. This development was incorporated into this process development program as it evolved. Therefore the wet chemical (chromic-phosphoric acid etchant) smear removal process will probably not be needed or applied here to Production use. However, it should still be useful to some other plants if they fail to obtain the plasma smear removal capability. Examples of flexible printed printed wiring (FPW) through holes plated after the dry plasma smear removal process are shown in Figures 7.3 and xxii.

7.4.4 Plasma Smear Removal

An alternative "dry" plasma smear removal process is currently under investigation here at General Dynamics Pomona. This makes possible a major change in the basic line sequence for FPW fabrication. This recent development from a complementary IRAD program being pursued at General Dynamics, Pomona Division, has demonstrated that a gaseous plasma in a reactor chamber can effectively vaporize the organic materials which are the cause of smear in drilled holes. As this process is a clean, simple, three step technique compared to the chemical chromic acid technique for removing smear, it has tentatively been designated as the first choice in the base line process. Although this did not impede the process proofing of representative hardware (it may even have expedited processing because of the simplified technique) extensive verification of the effects of the plasma on the basic material properties were then required. A variety of test samples were run analogous to those used to verify the chromic acid approach. This added two months of testing to the original program. Because of the low labor effort involved, no additional cost to the contract was incurred. Several trips were made to the plasma chamber vendor's facility in Hayward, California, to verify operating parameters established on initial experiments, to further specify the production facility to be procured, and to process various test samples, including the Pilot Lot of eight production-prototype multilayer flex harnesses, with test patterns incorporated on each panel. The parameters of gas flow rates, wattage, chamber size, parts loading capacity, temperature, and process time were adjusted from initial operating ranges used on the earlier multilayer test patterns. Test samples of a variety of flex harnesses were satisfactorily etched in the designated ranges. The amount of smear removal obtained is easily controlled by the time of treatment. The amount required is somewhat dependent upon the drilling efficiency. The plasma smear removal eliminates the difficult problems of chromium poisoning of the electroless copper plating line, and chromate waste disposal and rinsewater treatments previously required for the wet chemical chromic acid type smear removal treatments. Since less manual operations are involved, improved reproducibility is an added benefit.

7.4.5 Development of Multilayer Laminations with Acrylic Bondply

7.4.5.1 Preliminary Results

Although many good laminations with the acrylic adhesives were obtained here, and also reported by verbal communication with DuPont, there were some blisters obtained in some laminations here with bondply materials that had been opened and stored at room temperature for several months. The lamination conditions recommended by the material supplier are also significantly different than those commonly used with

7.4.5.1 Preliminary Results (Cont'd)

the current Production materials. This is quite logical, since the adhesive systems are different. Generally, recommended pressures are lower, and temperatures are higher for the acrylic adhesive as compared to the epoxy and phenolic butyral adhesives. Lamination times are comparable. Moderate development was anticipated in this area. Further improvement in the process for drying the materials before lamination was also needed. Preliminary test laminations have led to increases from the early parameters in the laminating temperature (to 380^{o}F), laminating pressure (to 400 psi) and laminating time (to 40 minutes at temperature). Various procedures for drying the bondply before lamination were tested. Individual panels were laminated successfully for early processing tests. The first multiple platen (4 openings) press run, per conditions specified on prepared planning sheets, showed blistering. A series of individual laminations were then done, varying the conditions for each based on the prior results, until satisfactory lamination was again achieved. Evaluation of the results, extension of parameters in the direction of improvements, theoretical considerations, and vendor communication all provided the basis for further development. Effects of relamination on blistered panels was also checked. Results varied according to prior treatment (degree of cure). Although some blisters disappeared, relamination does not seem to be an adequate solution.

7.4.5.2 Lamination Improvements

A recheck of a four layer flex harness lamination of an SP 133-4025 panel without pre-baking the adhesive bondply again left some small blisters. Problems were encountered in earlier circulating air oven drying experiments, in trying to keep adhesive materials safely separated, and to keep them from curling and sticking together while hot. Vacuum drying operations, with an ordinary laboratory vacuum pump on single sheets of bondply, with release sheet still on one side (as received) provided three successive, successful laminations, with other conditions unchanged (except that longer tooling pins were obtained, which permitted use of four instead of three silicone rubber sheets). Next a group of four stacked sheets of bondply (with release sheets on) were dried together, unsuccessfully, since the escaping water vapor caused "blistering" and crinkling of the stack of bondply. Finally a group of four sheets were rolled up (without removing the release sheets) with a stainless steel mesh screen (normally used for silk screening) to separate the sheets for faster release of gases. This worked well, without crinkling, and provided four more successful laminations over a two week period after the vacuum drying operation. Eight four-layer panels of drill test patterns of GDP drawing SP 133-4025 were laminated, individually, for process development of the lamination and adhesive preparation operations. Two sets of eight each of four layer preliminary

7.4.5.2 Lamination Improvements (Cont'd)

test patterns of GDP drawing SP 133-4017 were also laminated during process development. These resolved the original problems of occasional blisters, as long as moisture and fingerprints on the adhesive surfaces are avoided during preparation for lamination.

7.5 PILOT LOT MULTILAYER FLEXIBLE PRINTED WIRING PROCESS DEVELOPMENT

As a final process evaluation, and to provide data for the yield and cost analysis, a lot of six of a typical multilayer FPW were fabricated using the processes and techniques developed herewith, and tested to the requirements of paragraph 6. It was intended that these tests would fully evaluate the new acrylic adhesive materials and processes when used to fabricate an existing missile multilayer FPW. All the requirements and test methods paragraphs referenced herein for the pilot lot FPW comprise the first article inspection of, and are from MIL-P-50884 Type B, Class two. No additional process development was required for the pilot lot, beyond those processes successfully established for the four layer test pattern FPW of GDP drawing SP 133-5047. The dry plasma smear removal process was used for both of the multilayer FPW fabrication groups.

7.6 PROCESS DEVELOPMENT CONCLUSIONS

The success of the two-layer, four-layer and pilot lot multilayer FPW indicated that the process development had been adequate for this stage of flex harness fabrication. The planned process development for this program was successfully completed in that all the individual steps of the proposed process have now been established. The basic technology has been defined. The additional plasma smear removal process development continues favorably. The wet chemical smear removal process is available as backup but should not be needed here. The individual steps that comprise the process have all now been satisfactorily demonstrated. The planning for processing representative parts through the entire process has been prepared and used for the pilot lot. Results of both fabrication and testing have demonstrated the success of this program's process development plus the fortuitous parallel achievements in plasma smear removal.

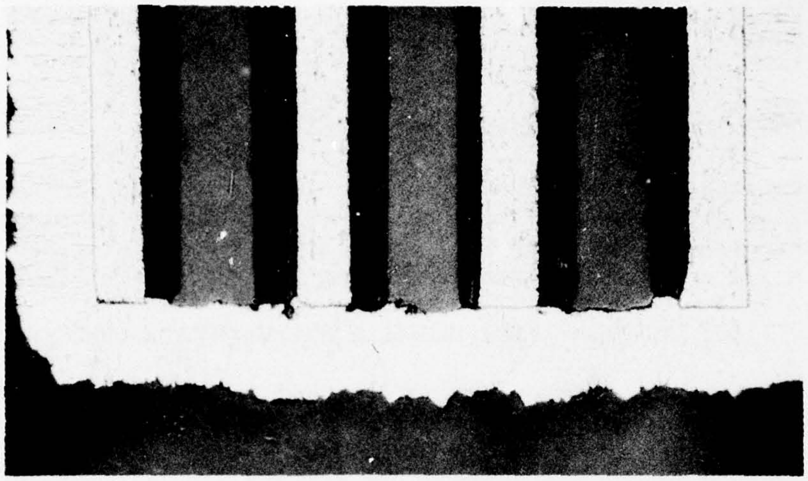

Figure 7-1. 200 X Cross Section of Acrylic FPW Hole Plated Through After Chromic-Phosphoric Acid Smear Removal

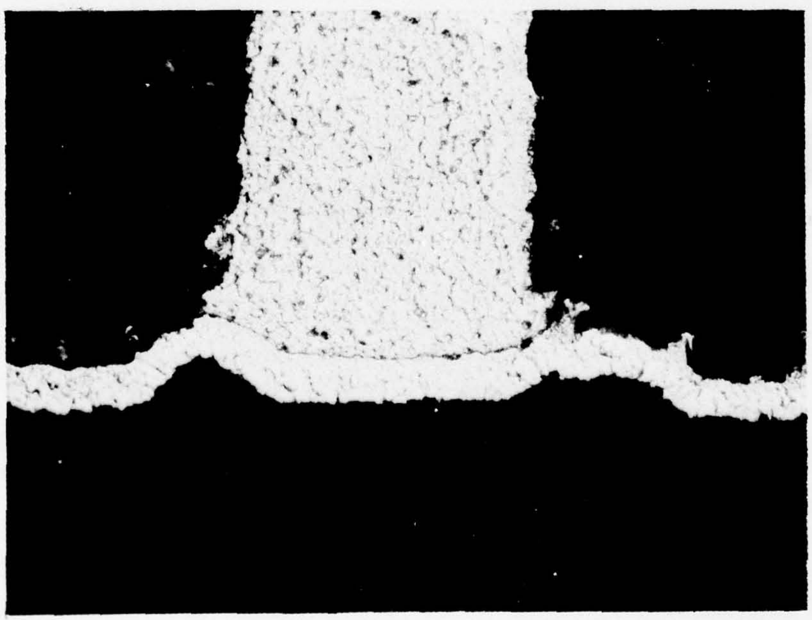

Figure 7-2. 500 X Cross Section of Acrylic-Polyimide-Copper Interfaces On Hole Wall of Multilayer Hybrid Plated Through After Chromic-Phosphoric Acid Smear Removal

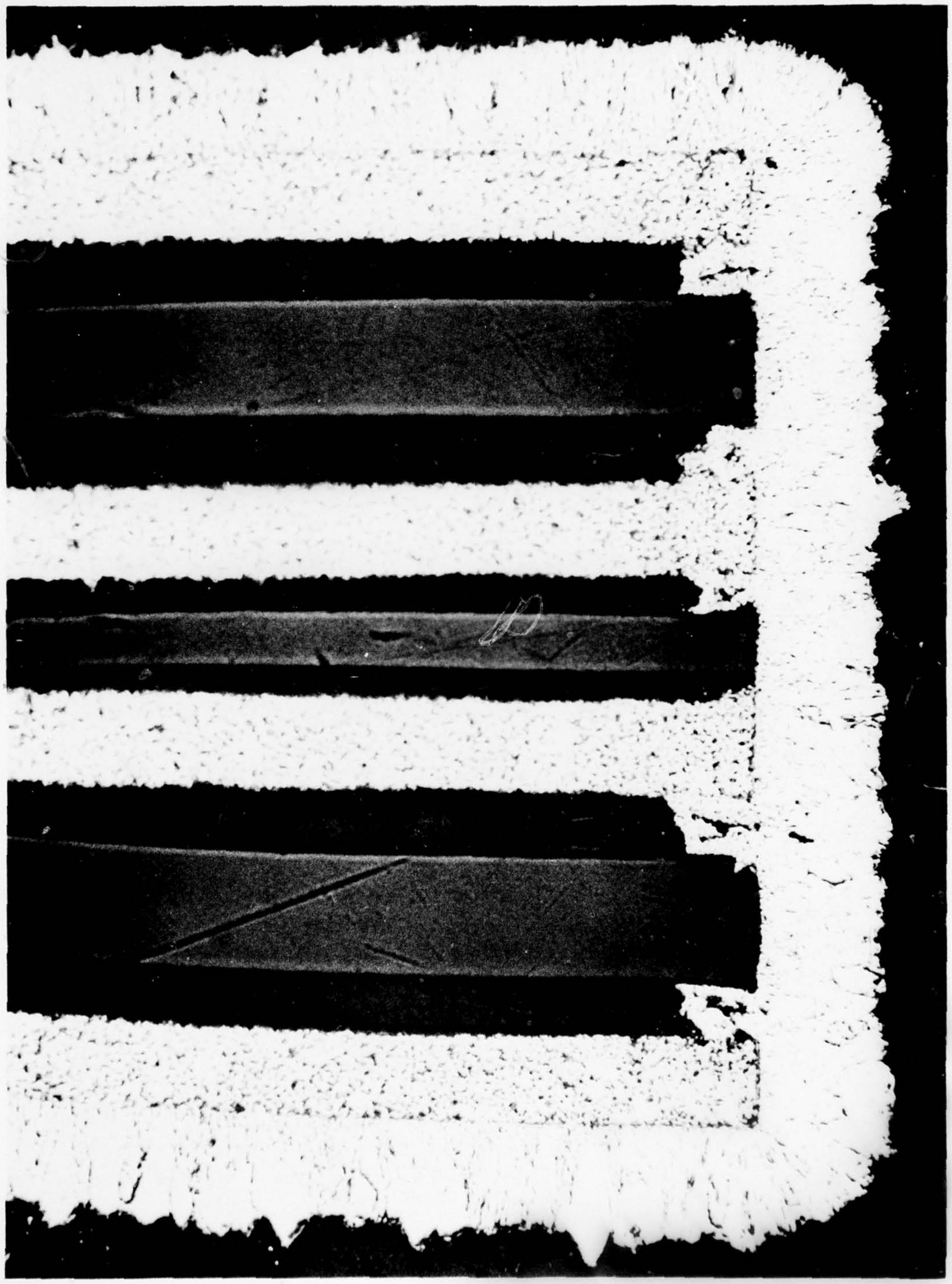

Figure 7.3. 400 X Cross Section of Hole in Acrylic-Polymide-Copper FPW Plated Through After Plasma Smear Removal

8.0 FABRICATION OF MATERIAL AND FPW TEST SAMPLES

Selection and Procurement of materials was the initial step. Sources were sought and considered throughout the year preceding the formal start of this contract, during the proposal and negotiation periods. The most appropriate acrylic-based adhesive materials available for production of flexible polyimide printed circuitry were procured. Sufficient material was on hand to initiate preliminary testing, and additional materials were procured as needed. This was not schedule-limiting.

8.1 FOR MATERIALS TESTS

8.1.1 Total Copper Removal by Etching

Copper was removed from copper clad laminate as required by etching in an acidified ferric chloride etchant at 130°F. Samples requiring total copper removal were not coated with photoresist.

8.1.2 Removing Adhesives

Adhesives were removed from either formerly-clad laminates after etching or adhesive coated polyimide insulation sheets by prolonged immersion in methyl ethyl ketone (MEK) at ambient temperature, until the adhesive was loose enough to peel readily.

8.1.3 Print and Etch of Clad Laminates

Two dry film photoresists formulated for use with aqueous solution strippers from different vendors (DuPont's Riston II and Dynachem's Laminar A) were both used successfully for patterned etching of the Method C peel test strips (paragraph 10.1.6), the adhesive flow test pattern (SP 133-5055), and the electrical test pattern (SP 133-5020).

8.1.4 Laminations of Peel Strength and Adhesive Flow Test Samples

For all of the materials tests, laminations were performed per recommendations of the respective vendors. This included time, temperature, pressure, starting temperature, and cooling prior to pressure release. Parameters were aimed at the midpoint of vendor-suggested ranges. The prime exception was the early lamination for peel strength of "completely untreated" polyimide to coverlay and bondply. This "untreated" was interpreted to exclude pre-baking also, and all materials gave poor adhesion.

8.1.4 Laminations of Peel Strength and Adhesive Flow Test Samples (Cont'd)

In later tests of the acrylic film adhesive, the bare polyimide (the uncoated side of scrap phenolic butyral coverlay) was pre-baked (which the acrylic vendor recommends for all materials in the lamination, but which would be dangerous with either the phenolic butyral or modified epoxy adhesives system, since both contain solvents and polymerizing agents). This prebaking of the polyimide at 250°F for one hour greatly increased the peel strengths of untreated copper, epoxyglass, and other bare polyimide as laminated to bare polyimide with the acrylic film adhesive. The earlier tests were still justified, since one hope of this program was that one of the two new materials might even provide reasonable adhesion to the unbaked bare polyimide, which was already known to lack adhesion when laminated with the present system. Although this hope was not realized, the discovery that prebaking greatly improved adhesion of acrylic to bare polyimide resolves that problem appreciably. This is not important in FPW fabrication, but should be helpful in flex-rigid hybrid fabrication.

8.1.4.1 Modified Epoxy Material Test Laminations

Twelve 12" x 12" panels using Fortin modified epoxy coverlay were laminated per vendor recommendations. Four panels each of three different layups were fabricated. These laminated coverlay to bare copper, coverlay to bare polyimide, and coverlay to epoxy glass. Bondply and film adhesive of modified epoxy were not included in this program.

8.1.4.2 Phenolic Butyral Materials Test Laminations

Thirty six 9" x 12" panels were laminated per vendor recommendations, using Rexham materials with phenolic butyral adhesive (with epoxy primers on coverlay and bondply). This consisted of four panels each of nine different layups. These nine different layups involved three materials (coverlay, bondply, and cast adhesive against bare polyimide) each of which was laminated separately to each of three other surfaces (bare copper, bare polyimide, and epoxy glass).

8.1.4.3 Acrylic Material Test Laminations

Twenty four 9" x 12" panels were laminated per vendor recommendations of lamination parameters using DuPont acrylic (Pyralux) materials. These consisted of four panels each of six different layups. The six different layups involved two materials (coverlay and bondply), each of which was laminated separately to each of three other surfaces (bare copper, bare polyimide, and epoxy glass). The supply of film adhesive had been used for other tests, and was reordered, so that those laminations were done separately a month later.

8.1.4.4 General Lamination Parameters and Uses

All of the bare copper and epoxy glass for the preceding seventy two panels were cleaned and baked identically. The uncoated side of some clean, scrap, phenolic butyral coverlay was used without any chemical or thermal treatment for the "untreated polyimide", identically for all of the above peel strength test laminations. Panels representing these eighteen different layups were submitted for the various peel tests outlined in the "Test and Evaluation Plan" (Reference 7) for the nine different test conditions listed herein in the following paragraphs: 6.3.4.1, 6.3.4.2, 6.3.4.3, 6.3.5.1, 6.3.5.2 and 6.3.5.3. This represents six adhesive materials, times three lamination surfaces, times nine test conditions equals 162 different sets of test parameters above for basic material peel tests.

8.1.4.5 Cast Acrylic Material Test Laminations

The remaining twelve 9" x 12" panels for materials testing were laminated as four each of three different layups. Each layup involved cast adhesive with bare polyimide on one side, and with the other side being bare copper, bare polyimide, or epoxy glass. Lamination parameters were per vendor recommendations. However, since the cast adhesive does not include polyimide, prebaking of the cast adhesive did not seem necessary and was not done. No blisters were observed. Since none of the laminations with the "untreated polyimide" of the previous eighteen different layups gave acceptable peel strengths, the "bare polyimide" for these acrylic film adhesive tests was pre-baked at 250°F for one hour, along with this standard practice pre-baking of the bare copper and epoxyglass. The bare polyimide side of scrap coverlay was used to provide the untreated polyimide surface. The release film as supplied on the other, adhesive side was left on to keep the coverlay sheets from sticking together in the oven. This release film was darkened by baking, but the peel strengths to bare polyimide were greatly improved by baking the polyimide prior to these laminations with acrylic film adhesive. Modified epoxy results were not affected, since this program did not include modified epoxy film adhesive. However, this does mean that results herein for "bare polyimide laminated to bare polyimide" with phenolic butyral film adhesive cannot be fairly compared to corresponding results with acrylic film adhesive. The process change was fortunate, though. It does provide a probable resolution to the serious problem of obtaining adequate adhesion to bare polyimide coverlay surfaces of subassemblies in flex-rigid hybrid fabrication, by use of acrylic adhesives. Special priming adhesives and operations have been required heretofore.

8.1.4.6 Pre-baking of Adhesives

In order to provide the closest comparison of the three adhesive materials and the least change of present Production standard practices. none of the adhesives were pre-baked for the peel strength test samples. Because of the solvents and polymerization accelerators, pre-baking is not recommended for the phenolic butyral and modified epoxy adhesives. However, the acrylic vendor's literature does include a statement to "pre-dry the bonding plies for ten minutes at 100°C (or 212°F)". Therefore it appears that the acrylic adhesives were done an unintentional and

8.1.4.6 Pre-baking of Adhesives (Cont'd)

hopefully slight injustice in not providing this extra baking step. This partially offsets the advantage described in the paragraph above for acrylic results with film adhesive between two bare polyimide sheets. The acrylic peel strength results were generally best anyway, even without prebaking. Finally, this would not effect the more important peel strength tests of vendor-laminated clad materials. Note that a vacuum pre-bake was used for the fabrication of all multilayer FPW in this study.

8.2 FABRICATION FOR TWO LAYER FPW

8.2.1 Requirements

The original plan was to fabricate two layer FPW in prescribed test patterns with technology selected from current practice, vendor recommendations, good judgement, and prior experience. If in-process examination of the results revealed visible delaminations, plating voids, or other cause for rejection, the process development above was to be extended as necessary by partial or complete fabrication of additional samples to provide visually acceptable panels for submission to test.

8.2.2 Preliminary Efforts

This fabrication effort preceded design and completion of tooling for the SP 133-5040 two layer FPW test pattern. In the meantime. the outer layers of other test patterns (SP 133-4017, SP 133-4018, and SP 133-4025) were used for preliminary process development and test panels. The drill tapes and planning were completed for the new two-layer test pattern SP 133-5040, and an eight panel series of these were cut, drilled, and submitted for electroless and electrolytic plating.

8.2.3 Fabrication Problems

Process development resolved those fabrication problems which appeared, primarily in smear removal, plating, and lamination. Some non-processing delays related to inspection and plating priorities were encountered and circumvented.

8.2.4 First Fabricated Test Panel

One SP 133-5040 two layer test panel was fabricated prior to coverlay design release. A simple coverlay pattern was laminated successfully, but the design was different than that later adopted to this panel was not included in the test data sheets to avoid an extra variable.

8.2.5 Four Remaining Parts of Two Layer Test Pattern SP 133-5040

Some plating problems arising during the conversion to a modernized automatic production plating plant, but not related in any way to these acrylic materials, eliminated the first set of two layer FPW test pattern SP 133-5040. These were replaced with a second set. Four two layer test pattern details for SP 133-5040 passed inspection. Coverlay drill and trim tooling were fabricated (different patterns front and back). Coverlay was drilled and trimmed, and these parts were laminated, tinned, and delivered for test.

8.3 FABRICATION FOR MULTILAYER FPW

8.3.1 Description of Multilayer FPW Fabrication

Groups of 9" x 12" test panels were fabricated from the selected acrylic materials as multilayer FPW. These consisted of four layers. Each multilayer was made from two double clad details. Each detail was etched on one side only before bonding the etched sides to each other with one bondply. The details were made from vendor-supplied laminates of one ounce copper bonded by acrylic adhesive onto each side of 0.002 inch thick polyimide. The bondply was 0.001 inch thick polyimide with the acrylic adhesive on both sides. Coverlay (0.001 inch polyimide thickness with acrylic adhesive on one side only) was laminated over some areas while others were left bare in accordance with the needs of the various tests. The nominal acrylic adhesive thickness was 0.001 inch for all materials (clad laminate, bondply, and coverlay) used for FPW fabrication in this study. These provided the samples for testing and evaluation of the product and process. Fabrication used whatever process development had been completed prior to each fabrication step. Portions of the Production facilities and personnel were used as practical to improve the producibility determination, and to illuminate typical Production difficulties which might otherwise not appear until later.

8.3.2 Multilayer Fabrication Sequence

The first multilayer flex harness test patterns which were fabricated were four layer flex harnesses without coverlay. Next, improved multilayer test pattern flex harnesses were fabricated. As the associated process development progressed with improvements in the plated through hole reliability and/or producibility, and from small pilot plant into larger processing tanks more related to production areas, retesting was required to confirm improvement or retention of desired test results.

8.3.3 Preliminary Fabricated Test Panels

Two SP 133-4017 four layer test patterns without coverlay were fabricated and submitted for some preliminary testing. Three series, each consisting of sixteen two layer flexible printed wiring "details", for lamination into eight each of three multilayer flexible printed wiring test panel designs (SP 133-4017,-4018, and -4025), were "photoetched" and inspected. A repeat series of one of these designs (-4017) was also etched. These series were laminated into multilayers, and drilled for use in development studies.

8.3.4 New Test Pattern Multilayer FPW SP 133-5047

Sixteen SP 133-5047 details were put in process under routine Production processing for drilling, print and etch, and inspection. All sixteen details for fabrication of the new multilayer FPW test pattern passed inspection, ready for multilayer lamination. Seven test pattern multlayer FPW were laminated (with no losses). A drilling anomaly affecting only one drill diameter, possibly resulting from a single drill bit either bent or improperly mounted, created a regular series of trangularly deformed holes. This creates a "worst-case" test, results of which may be considered along with the normal drilled holes. It should not noticeably affect planned tests except for hole cross section appearance, and is not related to the material differences in this study. Five of these multilayer FPW were processed through the new plasma smear removal process, electroless copper plating, and fluoboric acid copper electroplating. The five plated multilayer FPW were processed through the multilayer print and etch, and through coverlay lamination. All were submitted for multilayer FPW testing.

8.4 FABRICATION OF PILOT LOT MULTILAYER FPW SP 133-5067

8.4.1 Fabrication

The pilot lot of actual multilayer flex harnesses for first article testing was fabricated using latest process improvements and as much of Production facilities as was practical. Sufficient parts were fabricated to provide both for first article testing and for Engineering evaluation requirements. The Pilot Lot was existing multilayer flexible printed wiring selected by the Design Section from a military tactical weapon system. The materials used for the pilot lot were the same as those listed above (in paragraph 8.3) for the multilayer FPW test panels. Manufacturing planning was modified to reflect the process developed in this program. A combination of Production and Pilot Line Facilities were used, and personnel from Production, Manufacturing Engineering and Advanced Technology Development combined their efforts to fabricate the Pilot Lot.

8.4.2 Tooling Preparations

Additional test patterns were combined with a Standard production part artwork by Computer Aided Drafting for generation of photographic working tools, the first drill tape and secondary drill tapes. Glass masters were prepared, followed by glass plates with bushings aligned for internal layers. Planning drafts for details were completed first. Multilayer planning drafts were completed when drill data became available. This pilot lot was the final stage of this program fabrication schedule. The processing sequence planned for the pilot lot was documented.

8.4.3 Pilot Lot Fabrication

All fabrication was completed. The first set of eight pilot lot multilayer flexible printed wiring harnesses produced satisfactory parts. A back up set of eight parts, processed through lamination, second drilling, and X-ray, has likewise shown excellent results. The pilot lot samples used here for final proofing were processed through the factory on Engineering planning with steps such as drilling, print and etch and lamination done in the factory by factory personnel. Figure 8-1 shows the flexible printed cable assembly which included the FPW used for this pilot lot.

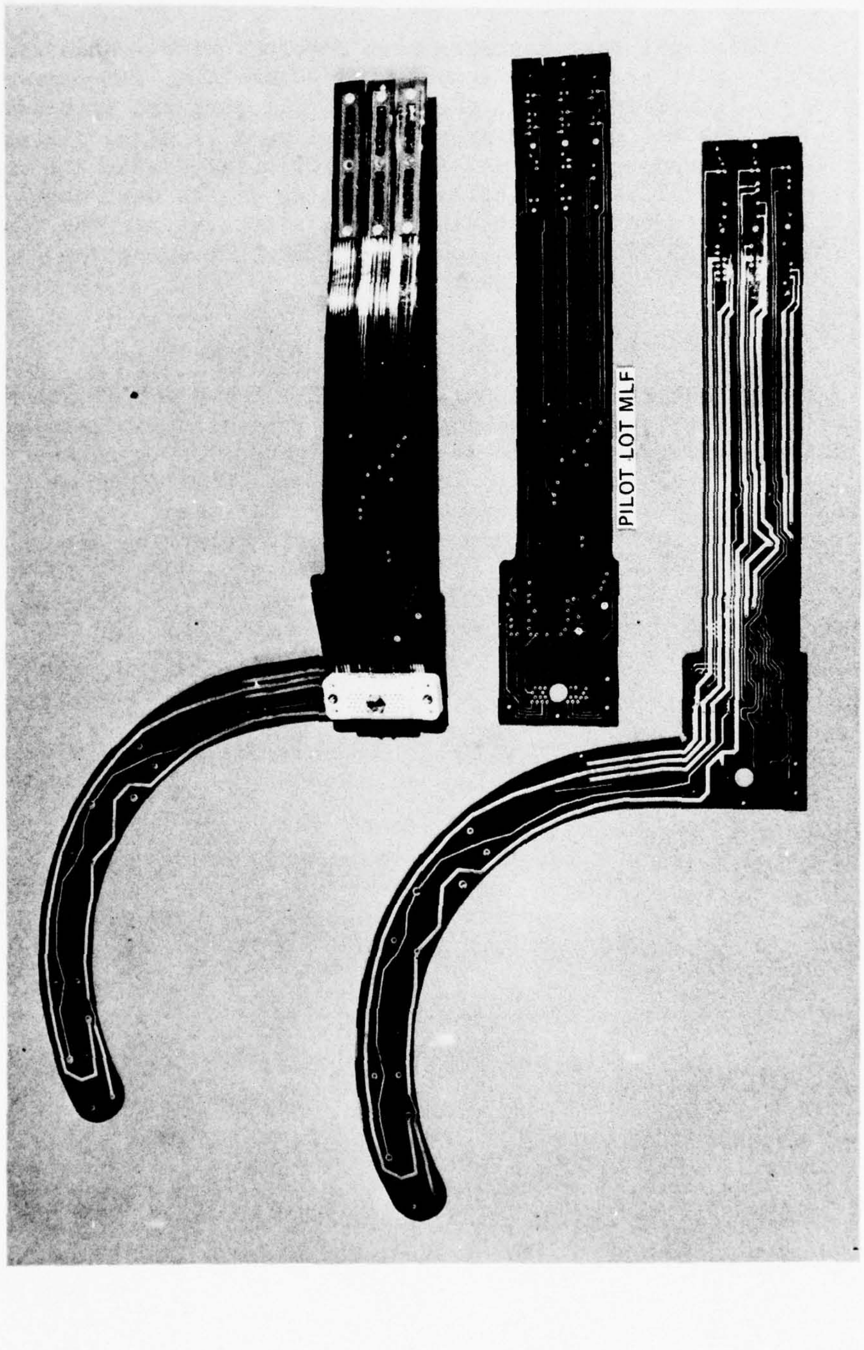

Figure 8-1. Printed Cable Assembly, Flexible, Including Pilot Lot FPW

9.0 PROCESS DESCRIPTION

9.1 PROCESS FLOW FOR OVERALL MLF PILOT LOT

9.1.1 All Materials

9.1.1.1 Furnish and Cut Material (-2,-3,-8 and basic)

Stack all cut materials between phenolic panels taped firmly.

*9.1.1.1.1 Pyralux LF91218 copper clad polyimide, bonded with acrylic for two inner layer details (-2 and -3).

*9.1.1.1.2 Pyralux LF0111 (GD 3244242-4) Acrylic-polyimide bondply for MLFH Lamination (-8).

*9.1.1.1.3 Pyralux LF0110 (GD 3244242-1) Acrylic-polyimide coverlay for MLFH (Basic Part No.)

9.1.1.2 First N/C Drill (-2,-3,-8 and basic) PDAD 030

Tooling, lamination, and alignment holes

9.1.2 Details

Send -8 and Basic to adhesive storage, continue -2 and -3.

9.1.2.1 Apply photoresist both sides (DuPont) MPS 120.24

9.1.2.2 Expose Both Sides

For -2, expose layer #2 vs. clear

For -3, expose layer #3 vs. clear

9.1.2.3 Develop Both Sides MPS 120.24

Leave protective film on solid side.

9.1.2.4 Touch up Both Sides MPS 120.47

9.1.2.5 Copper Etch Circuit Side Only MPS 120.26
For one ounce copper

9.1.2.6 Remove Resist Thoroughly MPS 120.43

9.1.2.7 Machine Scrub and Dry MPS 120.43

9.1.2.8 Inspect Details (-2 & -3) Per B/P

*Deviations from Standard Practice.

9.1.3 Lamination

Combine inspected -2 and -3 details with -8 Bondply.

*9.1.3.1 Vacuum Dry Bondply at 25" Mercury at 160° F For 30 Minutes.

Store in drying cabinet until used.

*9.1.3.2 Laminate per Lamination Log Book — MPS 120.41

Pre-bake details, go into and out of press at 150°F, laminate 40 minutes at 380°F, 400 PSI.

9.1.3.3 Drill .012 Alum entry and .093 Alclad backup — PDAD030

9.1.3.3.1 1/4 and 3/16 inch dia. tooling holes.

9.1.3.3.2 Drill alignment holes on Excellon drill. — N/C. Tape

9.1.3.3.3 Cut tooling holes from part edge.

9.1.3.3.4 Pin individual lamination between backup & entry.

9.1.3.4 Drill Lamination on Excellon Drill — PDAD 030, N/C Tape

Use series 265 drills, selected as specified.
Use feeds and speeds specified per PDAD.

9.1.3.5 X-Ray Each Multilayer Laminate

Submit any parts with unacceptable X-rays to inspection.

9.1.3.6 Machine Scrub and Dry — MPS 120.24

*9.1.3.7 Dry Plasma Discharge Smear Removal — MPS-TBD

9.1.3.8 Electroless Copper Plate — MPS 73.19

9.1.3.9 Electro-copper plate (submit A/R) — MPS 120.38

9.1.3.10 Machine Scrub and Dry For Photo Etch — MPS 120.24

9.1.3.11 Apply Photoresist Both Sides (DuPont) — MPS 120.24

9.1.3.12 Expose Outer Layers (#1 and #4) — MPS 120.24

*Deviations from Standard Practice

9.1.3.13	Develop Both Sides	MPS 120.24
9.1.3.14	Touch up Both Sides	MPS 120.47
9.1.3.15	Etch Copper (on Basis of Copper Thickness Per Plating A/R)	MPS 120.26
9.1.3.16	Remove Resist Thoroughly (includes automated rinse-dry)	MPS 120.43
9.1.3.17	Inspect - Layers 1 and 4	Per B/P

9.1.4 Final Multilayer Flex Harness

Combine inspected -8 lamination with "basic" drilled coverlay.

9.1.4.1 Trim Cutouts if required per B/P, in coverlay. — PDAD 040, Per B/P

*9.1.4.2 Laminate Coverlays to both sides of lamination per lamination log book, at 380°F and 400 PSI with four layers of rubber. Bake (-8) lamination but not coverlay. — A-BNTO, MPS 120.41

9.1.4.3 Immersion Tin Plate. Submit A/R. — MPS 73.62

9.1.4.4 Inspect

Coverlay lamination and immersion tin on exposed circuitry.

9.1.4.5 Trim to Size — Per B/P

Submit trim area to D/6-125 for extensive tests.

9.1.4.6 Inspect — Per B/P

Trim, lamination, damage, contamination.

9.1.4.7 Continuity Check — Per B/P

9.1.4.8 Inspect - Final

9.1.4.9 Forward to Engineering for Testing

*Deviations from Standard Practice

9.2 ADDED DESCRIPTION DETAILS FOR NON-STANDARD OPERATIONS

9.2.1 Lamination

9.2.1.1 Vacuum Dry Bondply

Moisture (water) in the stack of materials being laminated can instigate blisters and reduce peel strength of acrylic laminates. The water is most commonly present because of the natural tendency of polyimide to absorb water. This does not seem to be a problem with coverlay, presumably because that polyimide is on the outer surfaces, where steam can readily escape, while the bondply polyimide is trapped between the outer solid copper layers of the two details. A longer laminating cycle, or a preheat in the press without pressure, might provide an alternative solution, but these increase and might modify thermal expansion alignment problems. The vendor recommends drying "all materials" before lamination (ten minutes at 212°F) which would obviously include both the bondply and coverlay, and should achieve the desired result. However, there are some practical production problems in handling large quantities of hot, sticky adhesive, in order to keep them from curling excessively or sticking together. These are certainly not insurmountable, but are inconvenient in mass production. Separation of individual sheets in Teflon coated racks, or equivalent, is quite possible. The fact that the acrylic formulation used in Pyralux (by DuPont) is a "total solids" adhesive, as opposed to the more common solvent type epoxy and phenolic butyral formulations, suggested the possibility of vacuum drying to the principal investigator in this program. This was tested at a nominal temperature of 160°F for one hour with a simple (one step pump) vacuum oven at a minimum of "25 inches of mercury". The lower temperature for equivalent drying made possible by the reduced pressure reduces the softening and stickiness of the adhesive. However, it is still necessary to separate the adhesive sheets to permit free egress of moisture and to prevent localized sticking together, which then crumples the stack of sheets. This was easily achieved on the first try, by rolling up the individual sheets (in a large roll of about six inch diameter) in a stainless steel wire screen, of the type readily available for silk screening. In practice, a large number of sheets can be spread out (single thickness) on the unrolled screen on a table, then rolled up. The screen provides enough separation to permit moisture to escape. For larger scale operations, a screen could be stretched between two large rollers (separated as for a gigantic camera film cartridge). The drilled bondply sheets could be spread along the screen, between the rollers, as it was rolled onto one roll from the other. Then the single roll containing the bondply would be dried in the vacuum oven. The vacuum drying process worked very well, but has obviously not yet been optimized for production. Considering the value of multilayer FPW, a few minutes saved in vacuum oven

9.2.1.1 Vacuum Dry Bondply (Cont'd)

time, or a few degrees of oven temperature, is insignificant compared to the "insurance" value of an adequate pre-drying cycle. Since only the bondply needs vacuum drying, none is required for two layer FPW, and only one bondply per two coverlay sheets for the common four layer multilayer FPW, so if half of the FPW are multilayer, only 20% of the "adhesive coated insulation sheets" would require pre-drying.

9.2.1.2 Drying Other Materials Before Lamination

Etched clad laminate "details" (usually with two copper layers, with only the side which will become an inner layer etched before lamination) should always be dried thoroughly before laminating. One hour drying at 250°F is standard practice. This is usually done in a simple circulating air oven. If lamination tooling and vacuum oven space were both plentiful, equally good results could probably be obtained by completing the lamination layup, except for the top metal plates of the lamination tools (cauls), and vacuum baking the assembled stack. The top is left off and the stack should be loose enough to allow moisture to escape readily from between the multiple layers. This method could also be used with coverlay laminations, though the more common oven baking seems generally more economical. The coverlay was not pre-dried in fabrication of FPW in this program, although in the case of acrylic (solvent free) it could have been, with equal or better results. In fact, the comparative peel strength test results of acrylic versus the other two materials might have been even more impressive if pre-drying of coverlay had been included. It was discovered, as part of this program, that the peel strengths of acrylic adhesives to untreated polyimide were improved several fold when the untreated polyimide was baked at 250°F for an hour prior to lamination. With further optimization development, extensions of this approach, combined with chemical surface conditioning of the polyimide, might lead to still further increases in peel strength by the materials vendors.

9.2.1.3 Storage of Bondply Prior to Lamination

During the process development for this program, one vacuum dried batch of bondply was laminated separately over a week's time period. During this time, the bondply remained in an open hood, during a period of fairly low relative humidity, in a lamination room free of water tanks or aqueous processing. Results remained good throughout the week. However, in production, it seems common sense to store the drilled and vacuum-dried bondply in a "dry cabinet", at least. Since the bondply is drilled before the vacuum drying, there would be few occasions, in normal production, where the time interval between drying and lamination could be a problem.

9.2.1.3 Storage of Bondply Prior to Lamination (Cont'd)

Even then, a repeat drying should not damage the bondply. Some of the acrylic adhesives were in the plant for over a year prior to use, which is an appreciable advantage over the time limitations required on the current adhesive system.

9.2.1.4 Lamination Parameters

These also are not necessarily as yet optimized for Production, although a little extra time or temperature for lamination seems to be economical insurance for the still expensive and very important multilayer flex harnesses, especially while press capacity is not yet the limiting factor of Production output. Later, when yields and production rates are very high, Manufacturing Engineering studies to reduce the time and temperature requirements for lamination will be desirable, though certainly such routine cost reductions fall into the normal learning curve of continuing process development inherent in major contracts.

9.2.1.4.1 Lamination Temperature

For this program, a laminating temperature of 380°F was selected from the vendor's suggested range of 350-500°F. Lower laminating temperatures require more time for equivalent degree of cure. Generally lower temperatures might leave the harness more flexible, and somewhat less affected by moderate thermal aging effects, but the higher temperature should condition the harness to accept a somewhat higher thermal shock with less damage. More development is justified in this direction as flex harness requirements are extended in the future.

9.2.1.4.2 Lamination Pressure

A pressure of 400 psi was selected from the vendor's suggested range of 200 to 400 psi. This is still low compared with the 600 to 800 psi used for the phenolic butyral, so that the press capacity problem common at GDP in recent years on large FPW will be eliminated by change to acrylic adhesives, but 400 psi is also a high enough pressure to provide greater insurance and reliability in filling the sharp crevices completely with adhesive during laminations. Pressure optimization will vary, of course, depending upon design parameters such as thickness of copper, number of layers, bondply versus coverlay, thickness of polyimide and of adhesive, and even the thickness and type of release films (such as Teflon) and pressure pads (such as fiberglass-reinforced silicone rubber).

9.2.1.4.3 Lamination Time

The time at temperature was increased to forty minutes, compared to the vendor's suggestion of 10 to 30 minutes, because this also is cheap insurance. Typical heat-up and cooling times in the press total about 30 minutes anyway, so that the effective difference is between 40-60 minutes suggested and 70 minutes used herein.

9.2.1.4.4 Temperature at Application and Release of Pressure

Some lamination cycle time can be saved by placing the assembled stack into a hot press, and some laminations were started at 250°F, which should not damage any of the acrylic materials. However, there may be some side effects of differential fast thermal expansion between top and bottom cauls (lamination tool plates), or of too rapid formation of steam or other vapors within the stack. Therefore these test FPW, including the pilot lot, were laminated with a 150°F starting temperature. The temperature before release of pressure is much more important. All laminates were cooled to 150°F platen temperature (actual harness center temperature would be somewhat higher) before release of pressure. Otherwise trapped vapors may create blisters or gross delamination. Essentially, the materials are "frozen" or solidified enough to provide extra tensile strength, enough to resist any remaining vapor pressures. At the same time, the cooling period allows extra time during which remaining vapors may diffuse out of the part, and the lower temperature allows some types of vapors to condense again, or at least have lower vapor pressures.

9.2.1.5 Post Curing

In this program, a separate post-curing operation, such as is frequently used after laminations to increase degree of cure without tying up the available process time, was not used for two reasons. First, the high temperature exposure effects on all materials tested in this program were more severe than anticipated, so that there appears some risk from open-air curing of flexible printed wiring, far above that expected with rigid multilayer printed wiring boards. Second, a separate post-curing operation, which involves extra handling, extra planning, and extra equipment, seems more expensive at current production levels than simply increasing the time in the lamination press, since a longer press time involves no labor, and even minimal energy compared to heat-up and cooling periods.

9.2.2 Dry Plasma Discharge Smear Removal

9.2.2.1 Patent Applied For

This is a GDP development devised by E. Phillips in a chronologically parallel, company-funded, research study. The details will therefore not be included herein, though a published article on this topic is expected within a few months.

9.2.2.2 Operating Equipment

The equipment required physically resembles a vacuum drying oven with the additions of controlled environment and electrical plasma discharge provisions.

9.2.2.3 Operating Labor

Control of equipment and environment are required, and parts must be suitably racked and spaced, but the manual operations and time cycles are not unlike vacuum drying operations. Since there are few manual operations compared to the extensive chemical processing line required for typical wet chemical smear removal operations (such as for chromic acid smear removal), extensive cost savings and yield improvements are anticipated from the dry plasma discharge smear removal process.

9.2.3 <u>Alternative Wet Chemical Acrylic Smear Removal Process</u>

The chromic acid smear removal and electroless copper plating processes previously used for phenolic butyral FPW fabrication are completely inadequate for acrylic multilayer FPW fabrication. There is no difficulty in fabricating two layer FPW of acrylic materials, since chemical smear removal is not essential for two layer FPW. Others have managed to produce multilayer acrylic FPW by using mechanical smear removal methods (such as extensive liquid honing) but these are not generally considered an adequate resolution of the smear problems. A successful chromic acid smear removal process was devised in this program, and has been presented at 1976 NEPCON conferences. However, the dry process of plasma discharge smear removal is expected to require much less chemical control and processing labor for comparable results, and should therefore provide a higher yield and reliability in normal Production practice. The wet chemical method is discussed in detail in Appendix II.

10.0 HARDWARE AND TOOLING DESCRIPTION

TABLE XVII; SUB-INDEX OF SECTION 10, HARDWARE AND TOOLING DESCRIPTION

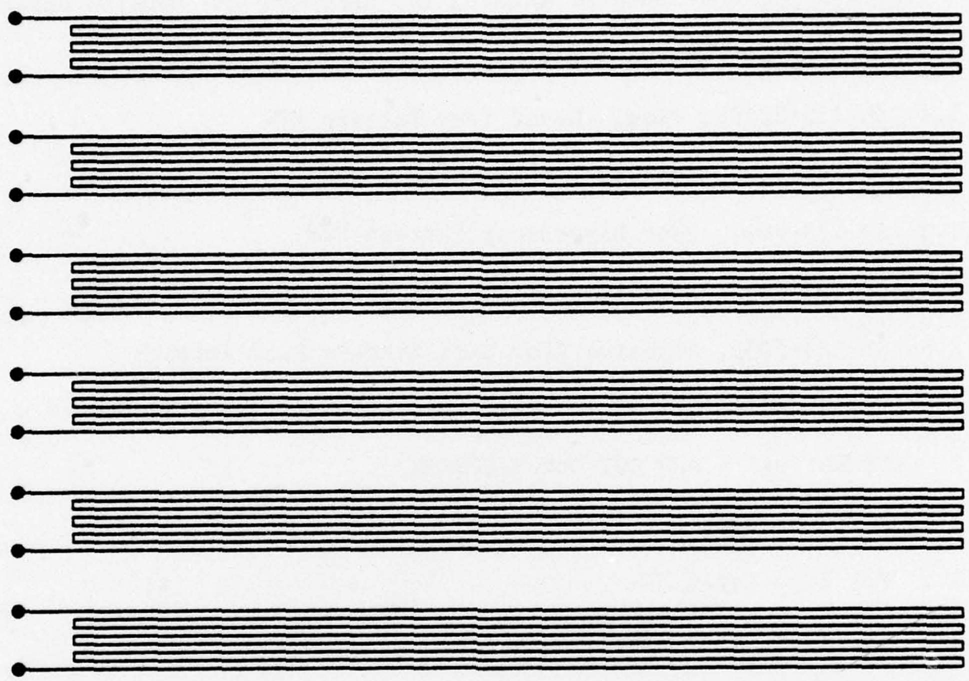

Figure 10.1.1. SK 133-5020 H, Single Layer Test Pattern FPW

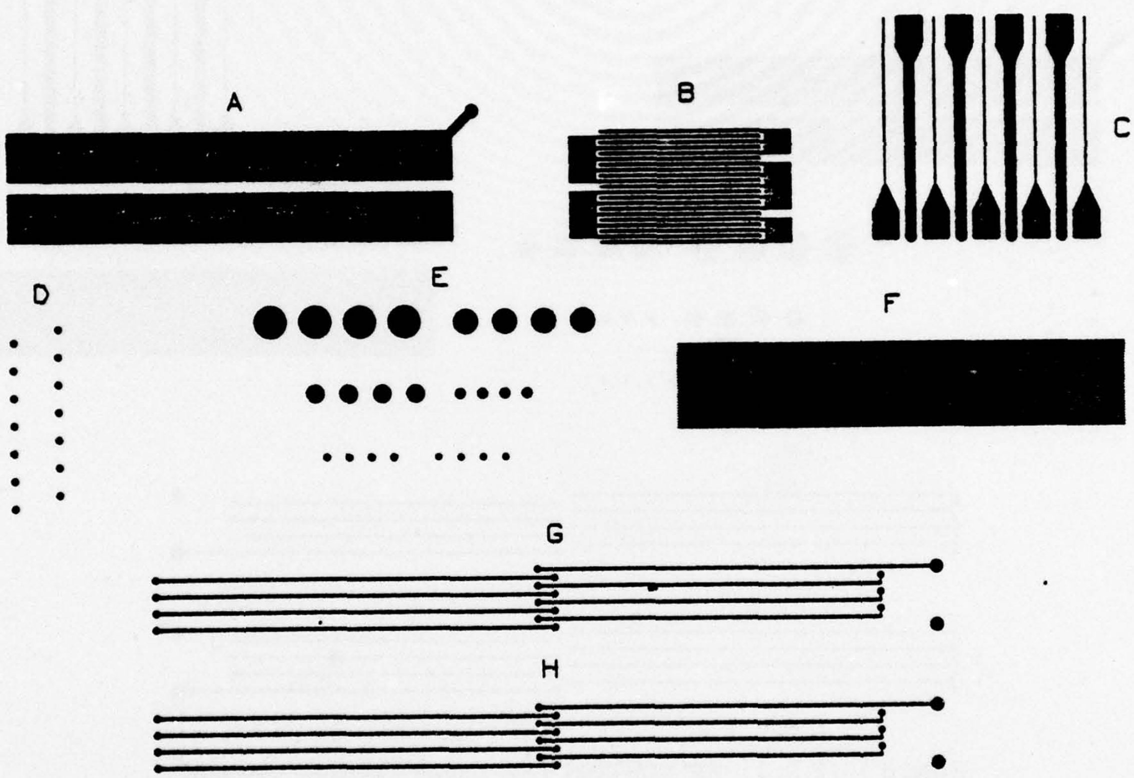

Figure 10.1.2.1. SP 133-5040, Two Layer Flexible Printed Wiring Test Pattern (FRONT)

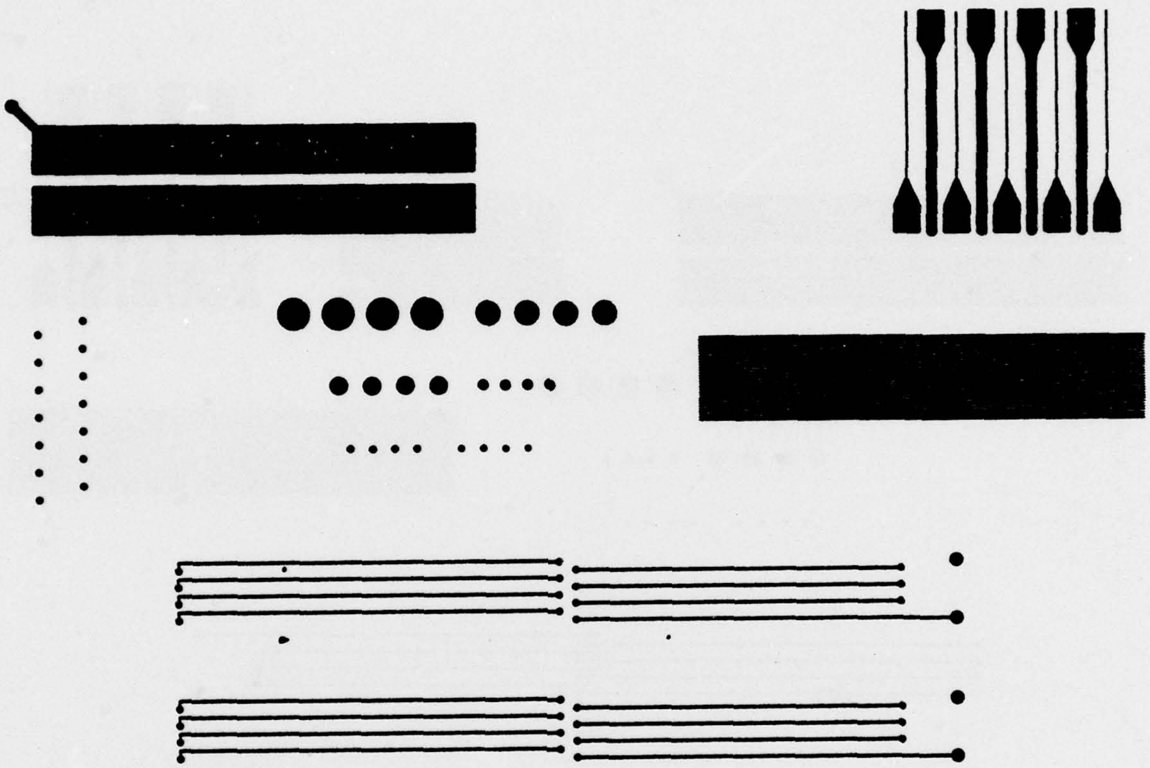

Figure 10.1.2.2. SP 133-5047 Two Layer Flexible Printed Wiring Test Pattern (REAR)

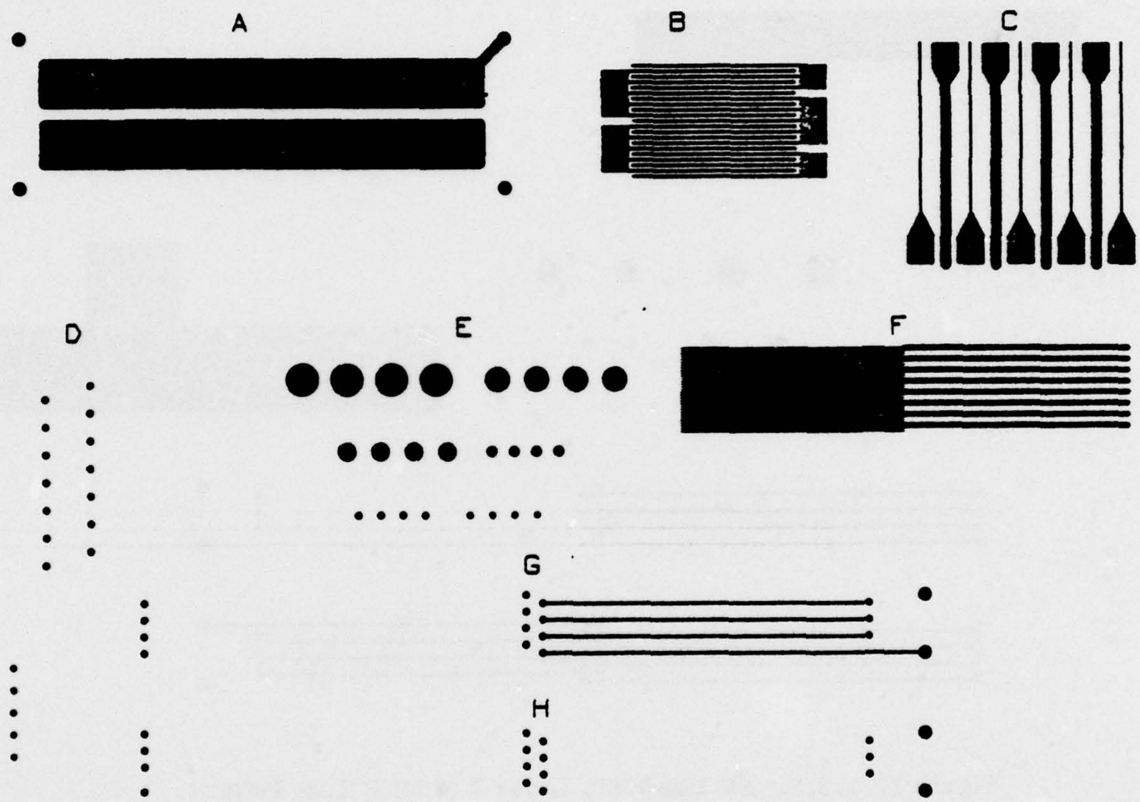

Figure 10.1.3.1. SP 133-5047, Layer 1 of Multilayer Flex Test Pattern

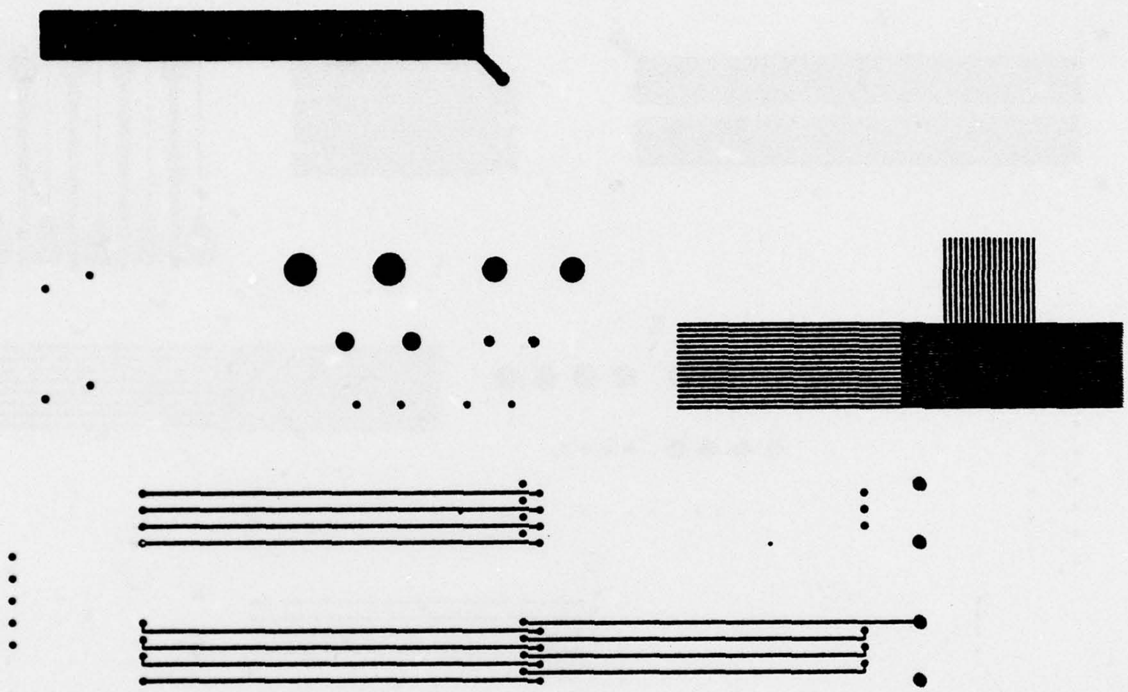

Figure 10.1.3.2. SP 133-5047, Layer 2 of MLF Test Pattern

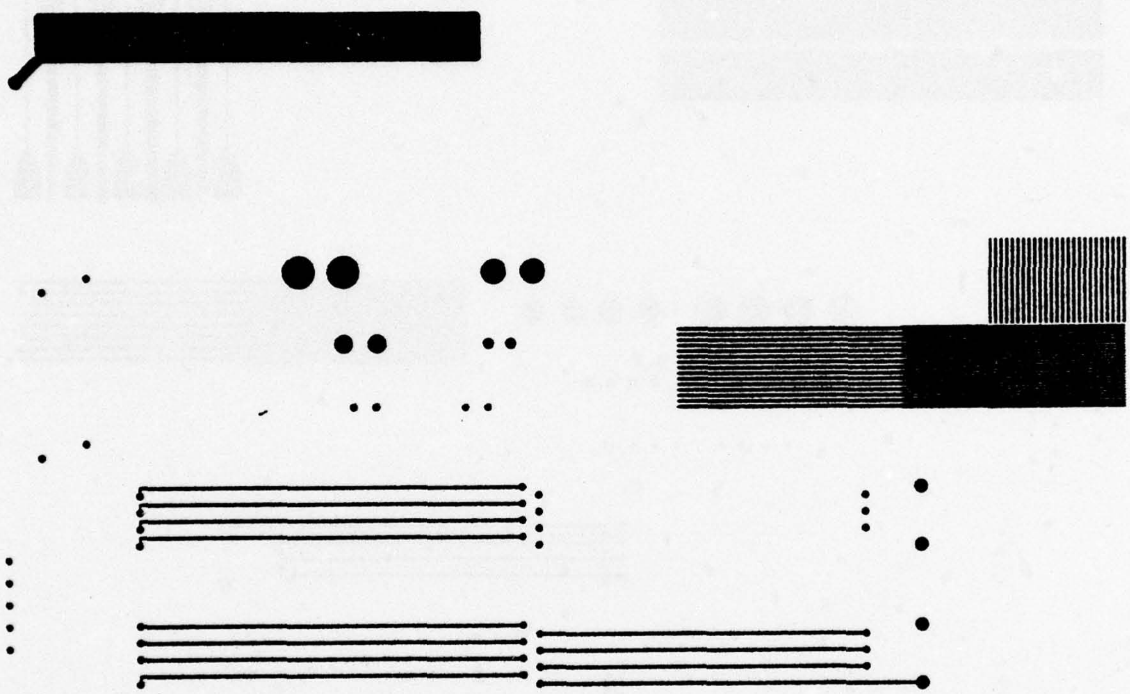

Figure 10.1.3.3. SP 133-5047, Layer 3 of MLF Test Pattern

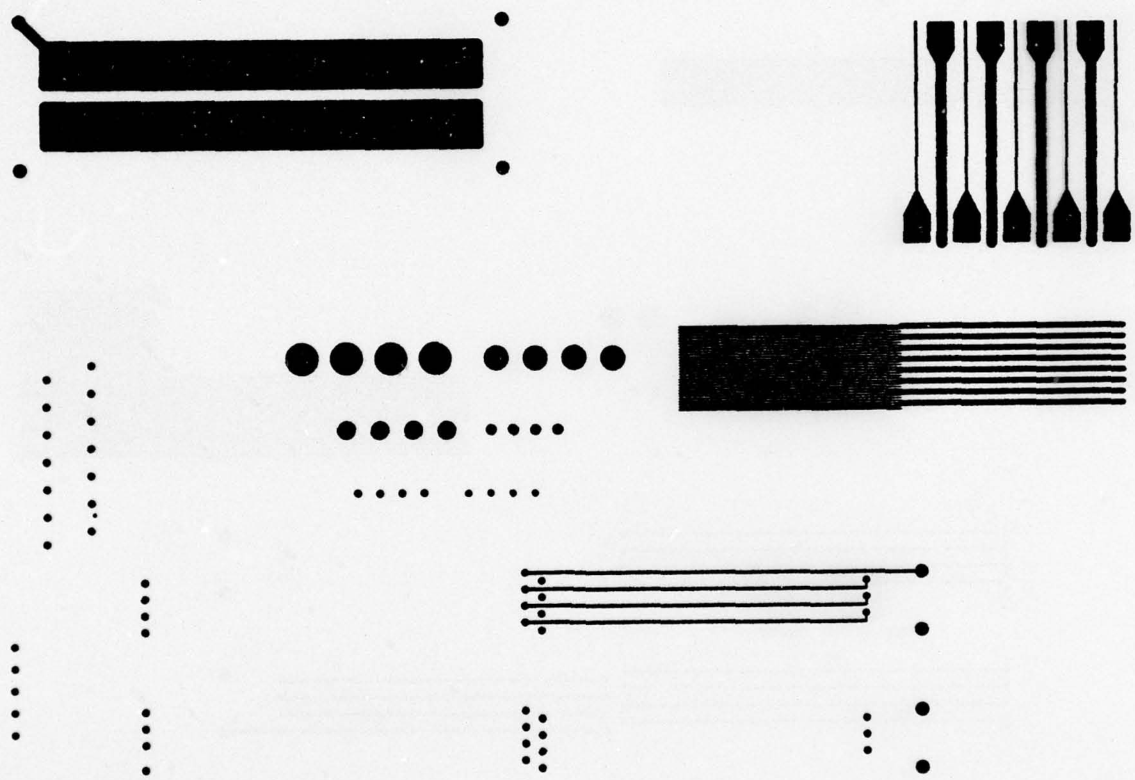

Figure 10.1.3.4. SP 133-5047, Layer 4 of Multilayer Test Pattern

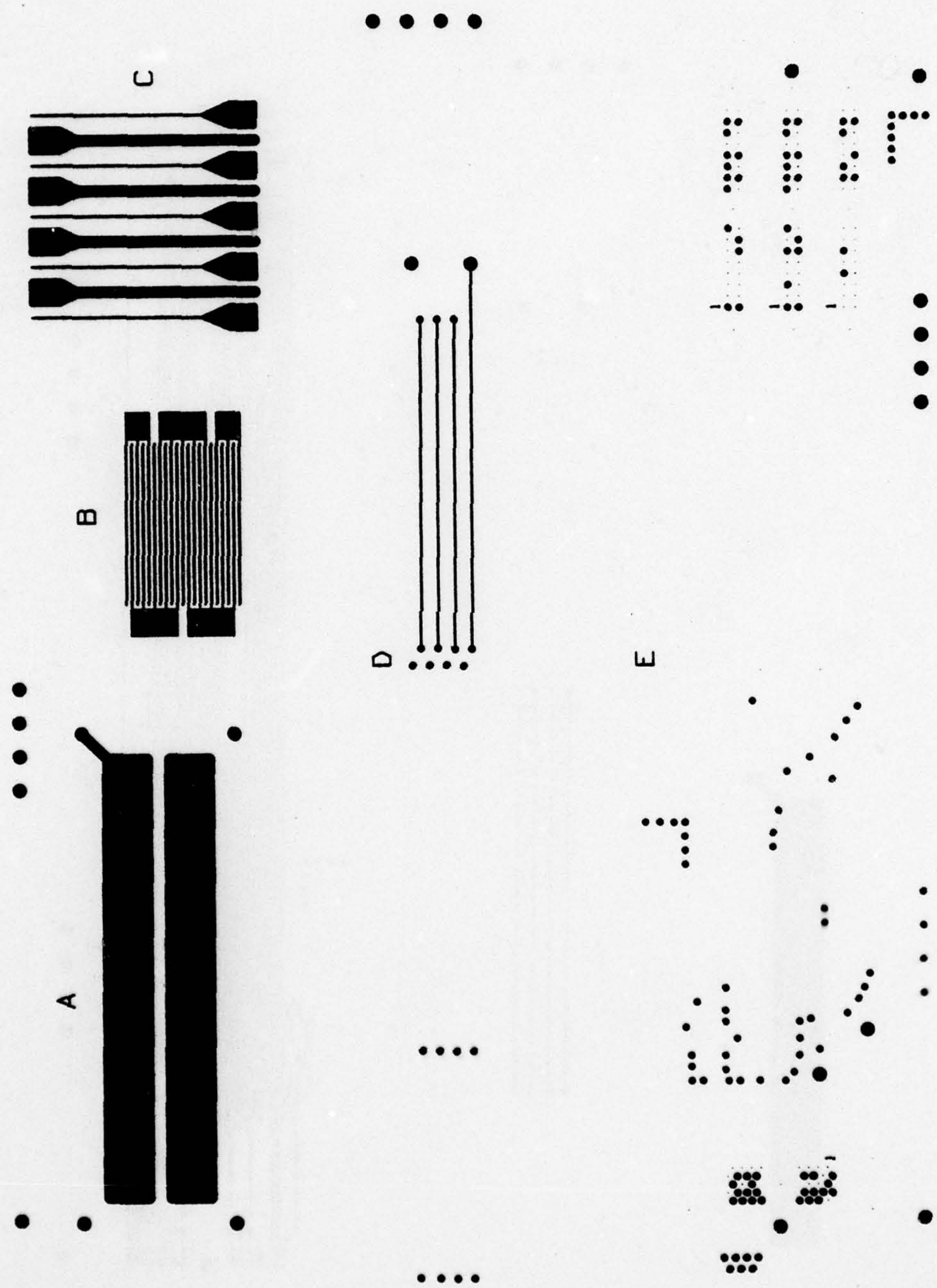

Figure 10.1.4.1. SP 133-5067, Layer 1 of Multilayer Pilot Lot FPW

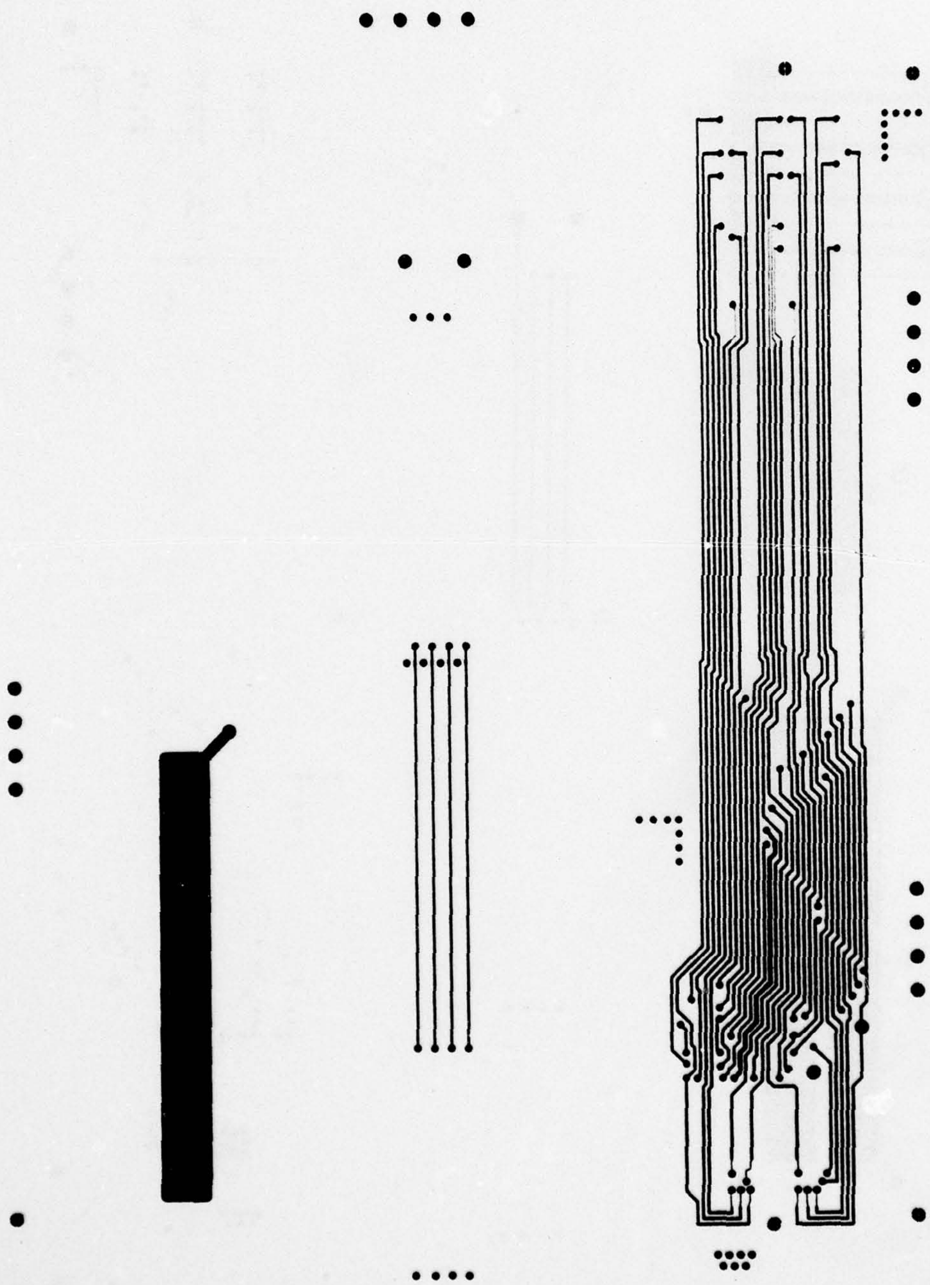

Figure 10.1.4.2. SP 133-5067, Layer 3 (REVERSED)

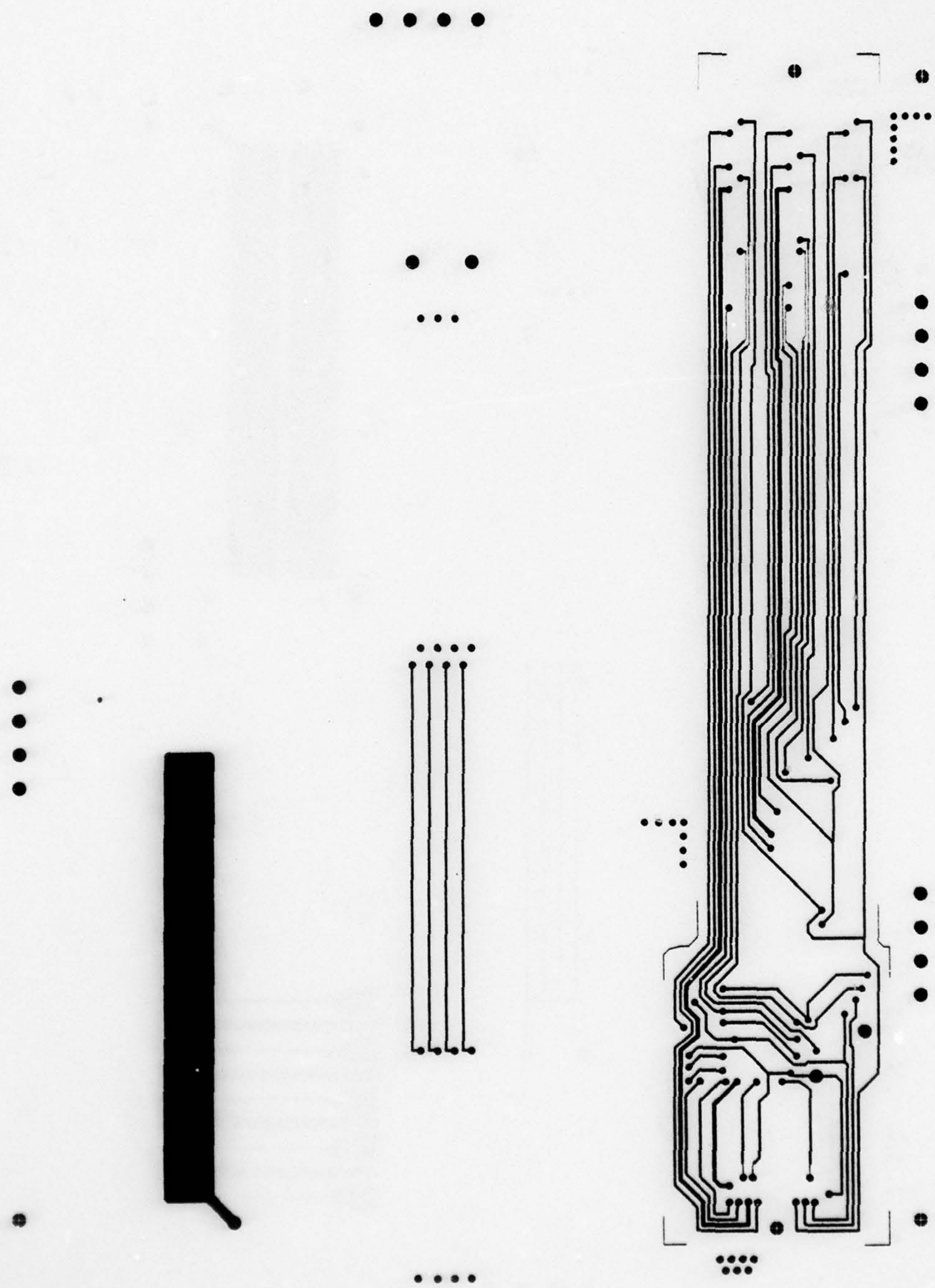

Figure 10.1.4.3. SP 133-5067, Layer 3

AD-A045 354 GENERAL DYNAMICS/POMONA CALIF POMONA DIV F/G 11/9
PRODUCTION PROCESS DEVELOPMENT FOR POLYIMIDE-ACRYLIC MATERIALS --ETC(U)
SEP 77 S A HAYS, W A SMITH, F K SAWYER N00123-76-C-0138
UNCLASSIFIED M-24-S-476 NL

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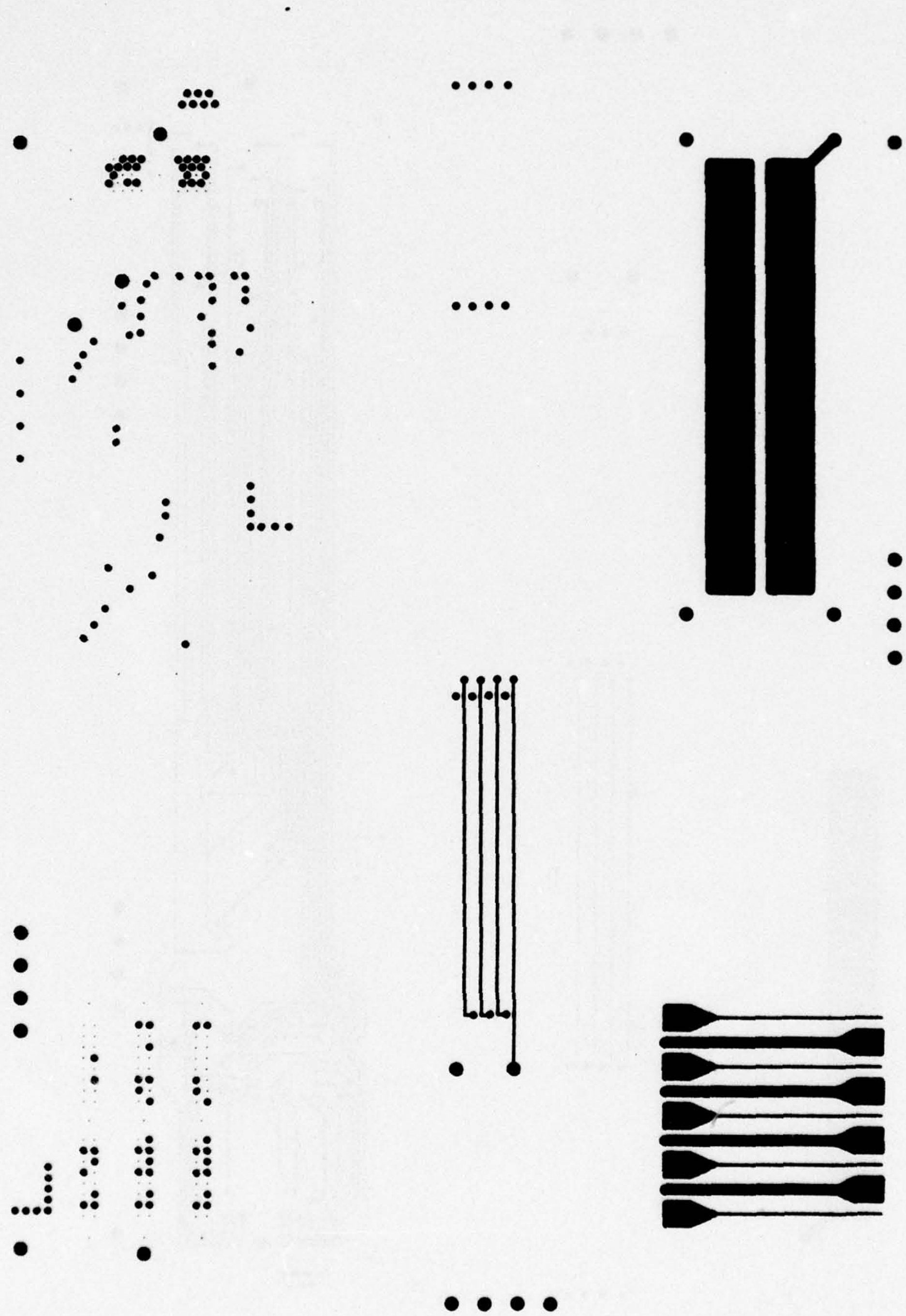
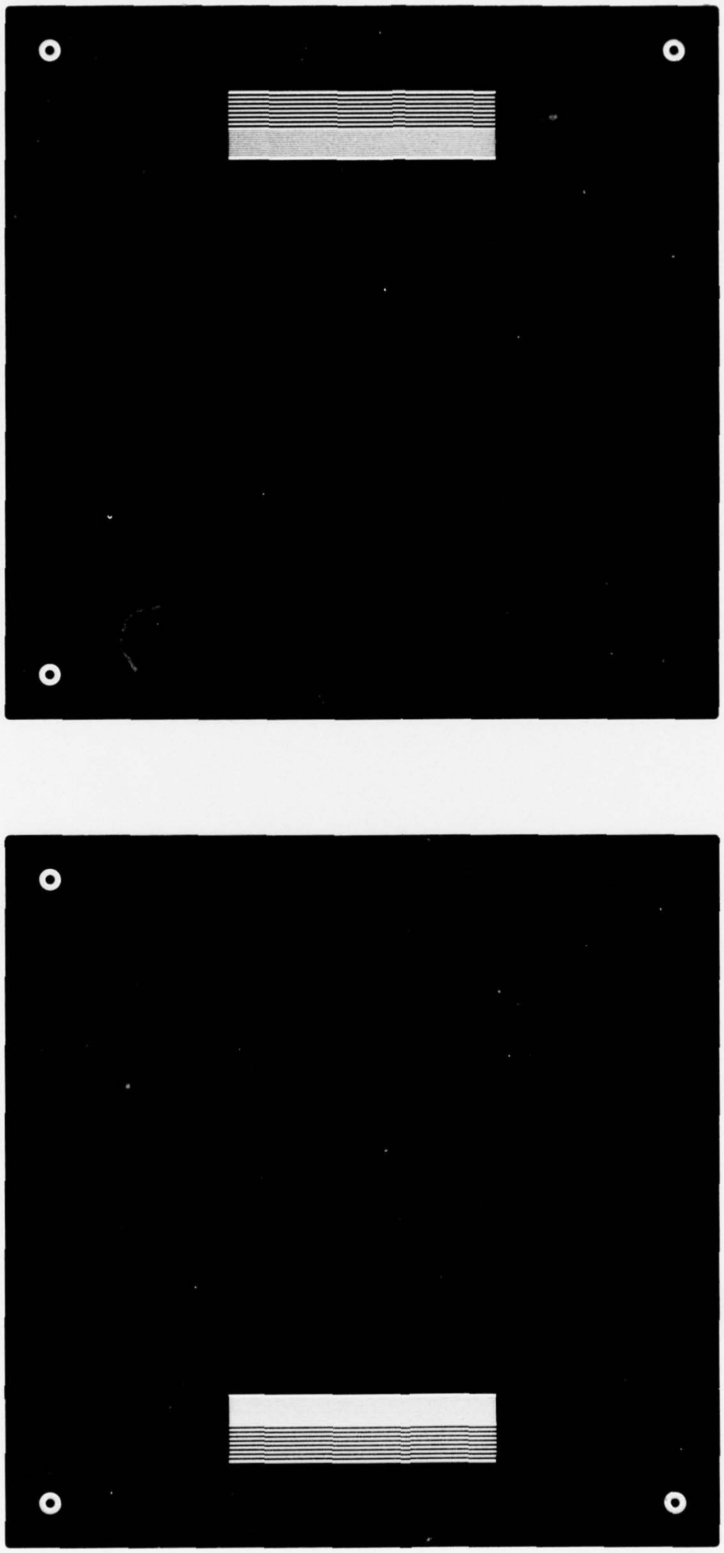


Figure 10.1.4.4. SP 133-5067, Layer 4 (REVERSED)



SP133-5055 TEST BOARD

12-16-75 PLOT 2138

Figure 10.1.5. SP 133-5055, Adhesive Flow Test Pattern Etch Artwork

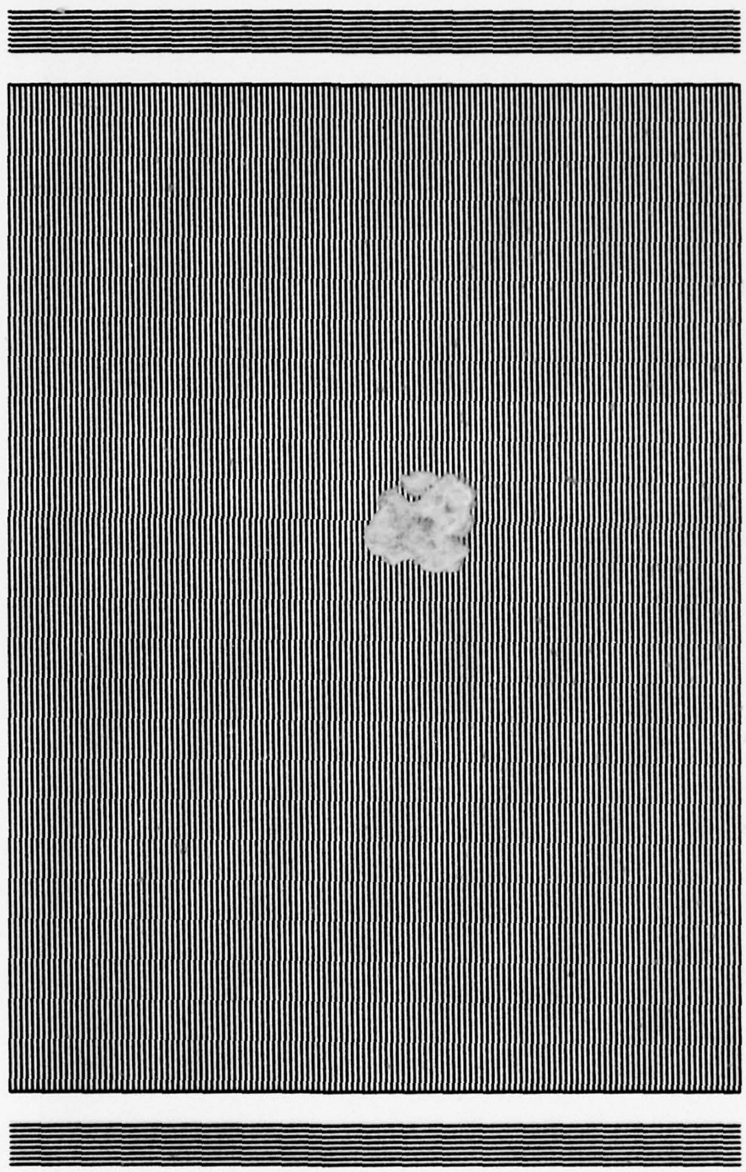


Figure 10.1.6. Design Prototype Test Plot Used for Peel Tests by Method C

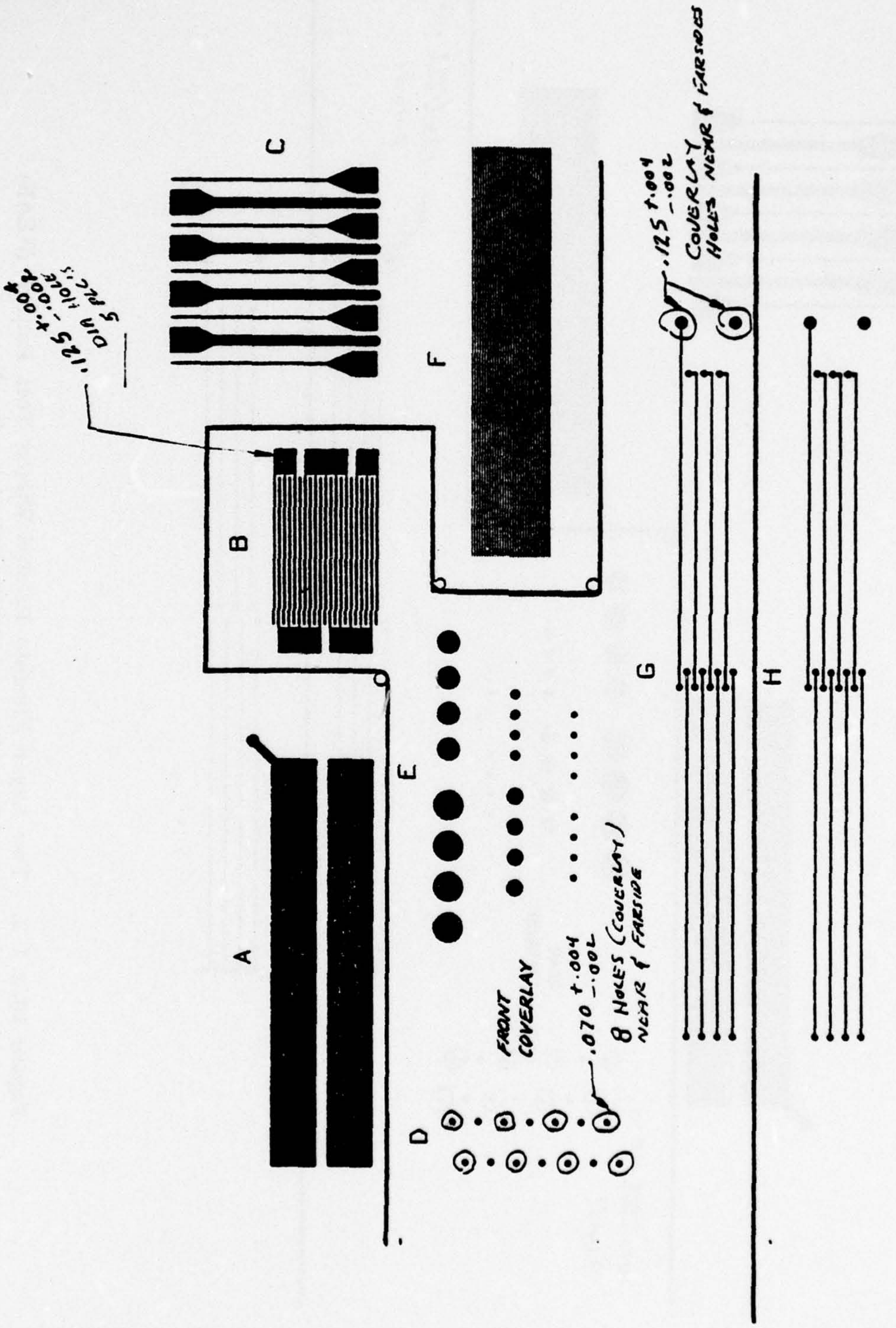


Figure 10.2.1.1. Two Layer Flexible Printed Wiring Test Pattern (FRONT) (Coverlay View with Adhesive Down)

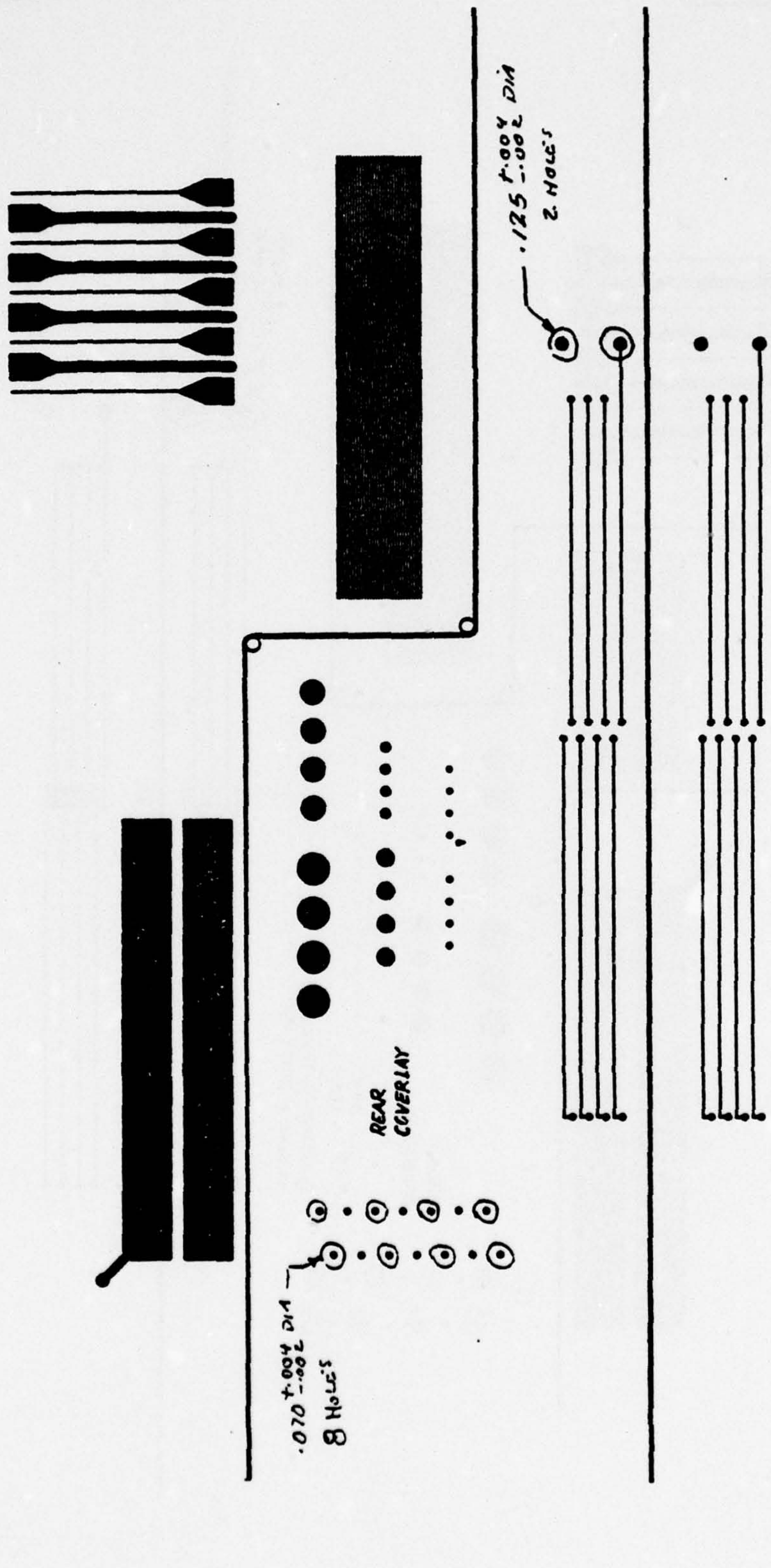


Figure 10.2.1.2. Two Layer Flexible Printed Wiring Test Pattern (REAR)
(Coverlay View Through FPW With Adhesive Up)

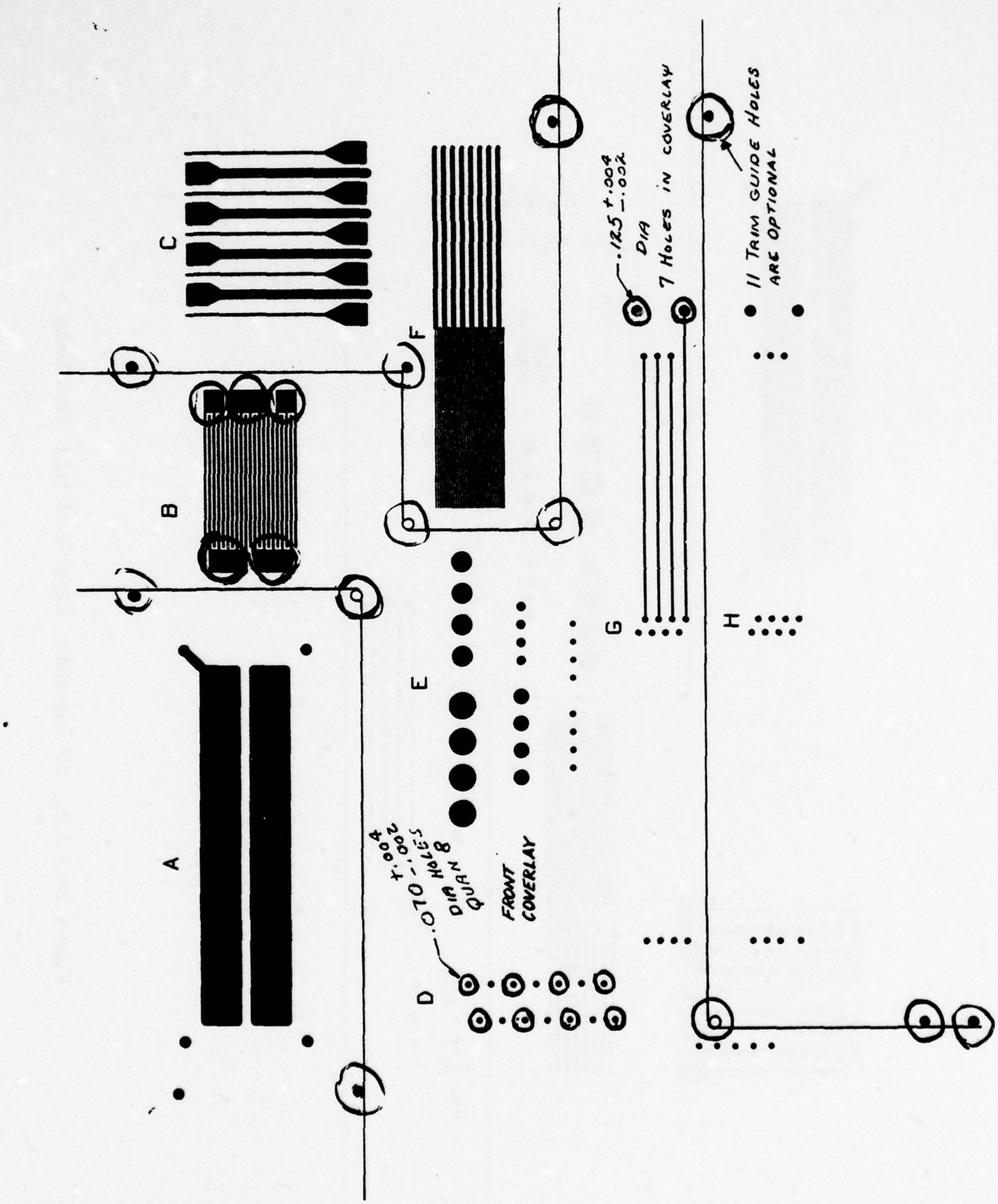


Figure 10.2.2.1. SP 133-5047, Layer 1 of Multilayer Flex Test Pattern

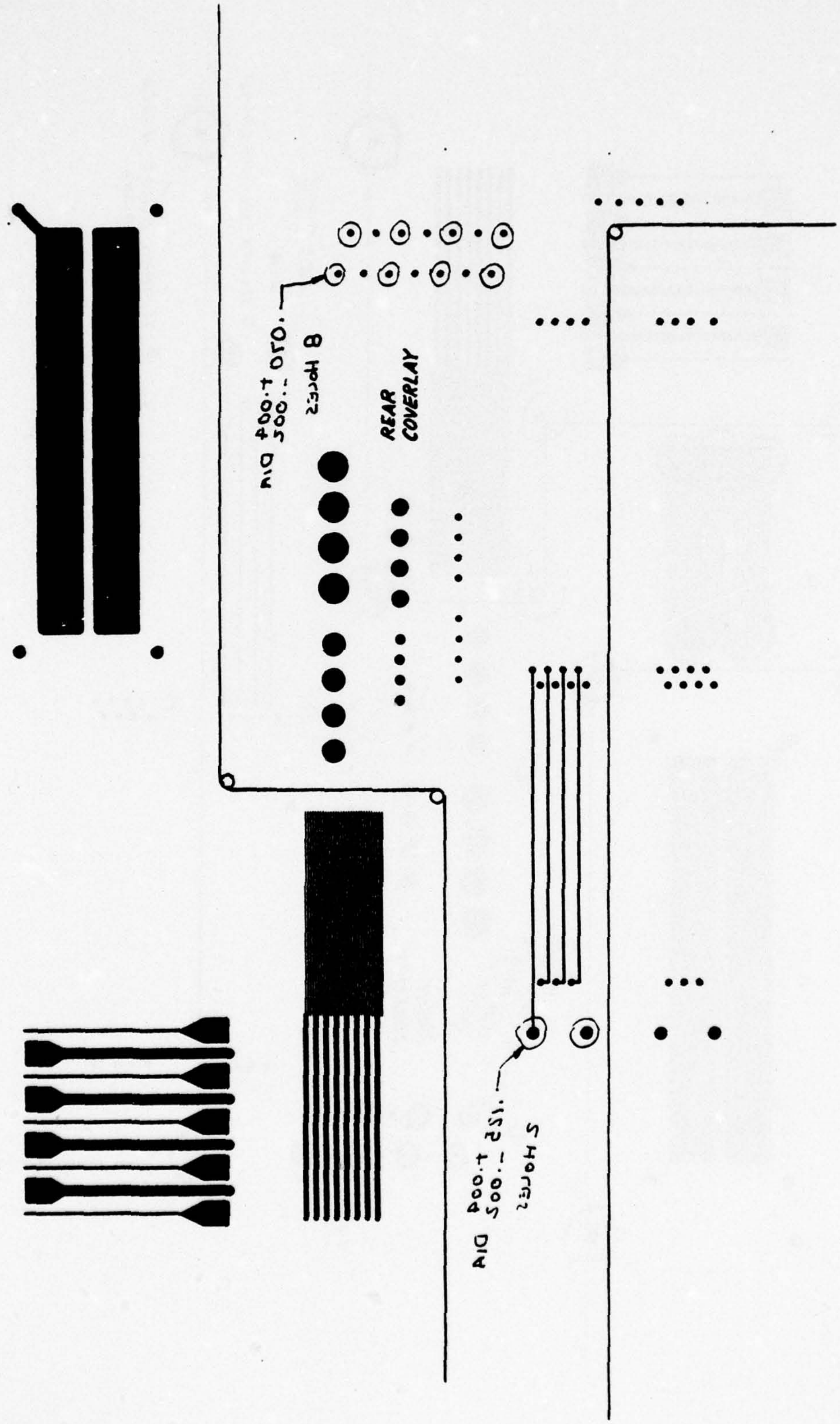


Figure 10.2.2.2. SP 133-5047, Layer 4 of MLF Test Pattern

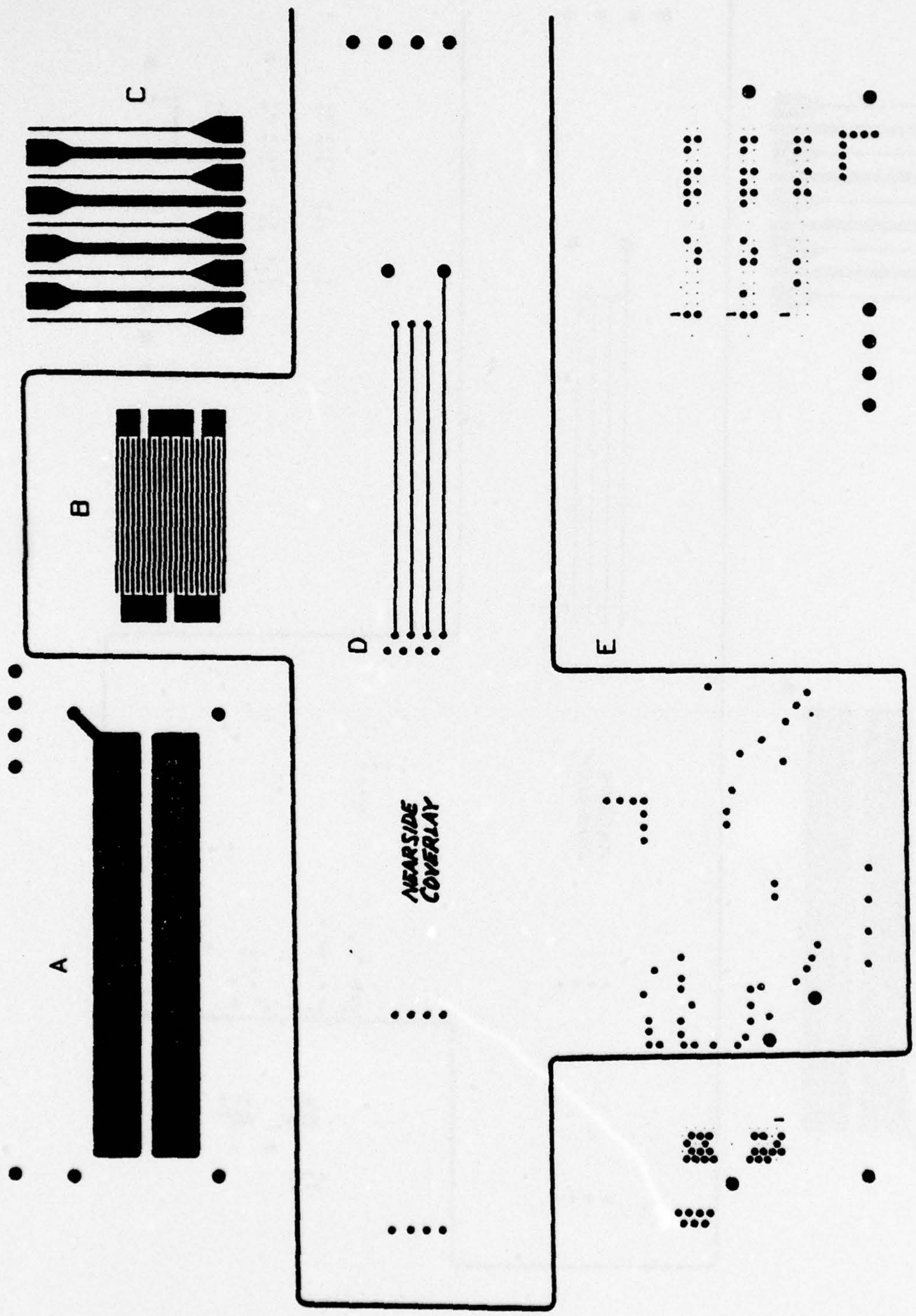


Figure 10.2.3.1. Nearside Coverlay Pattern for Multilayer Pilot Lot FPW (Coverlay View With Adhesive Down)

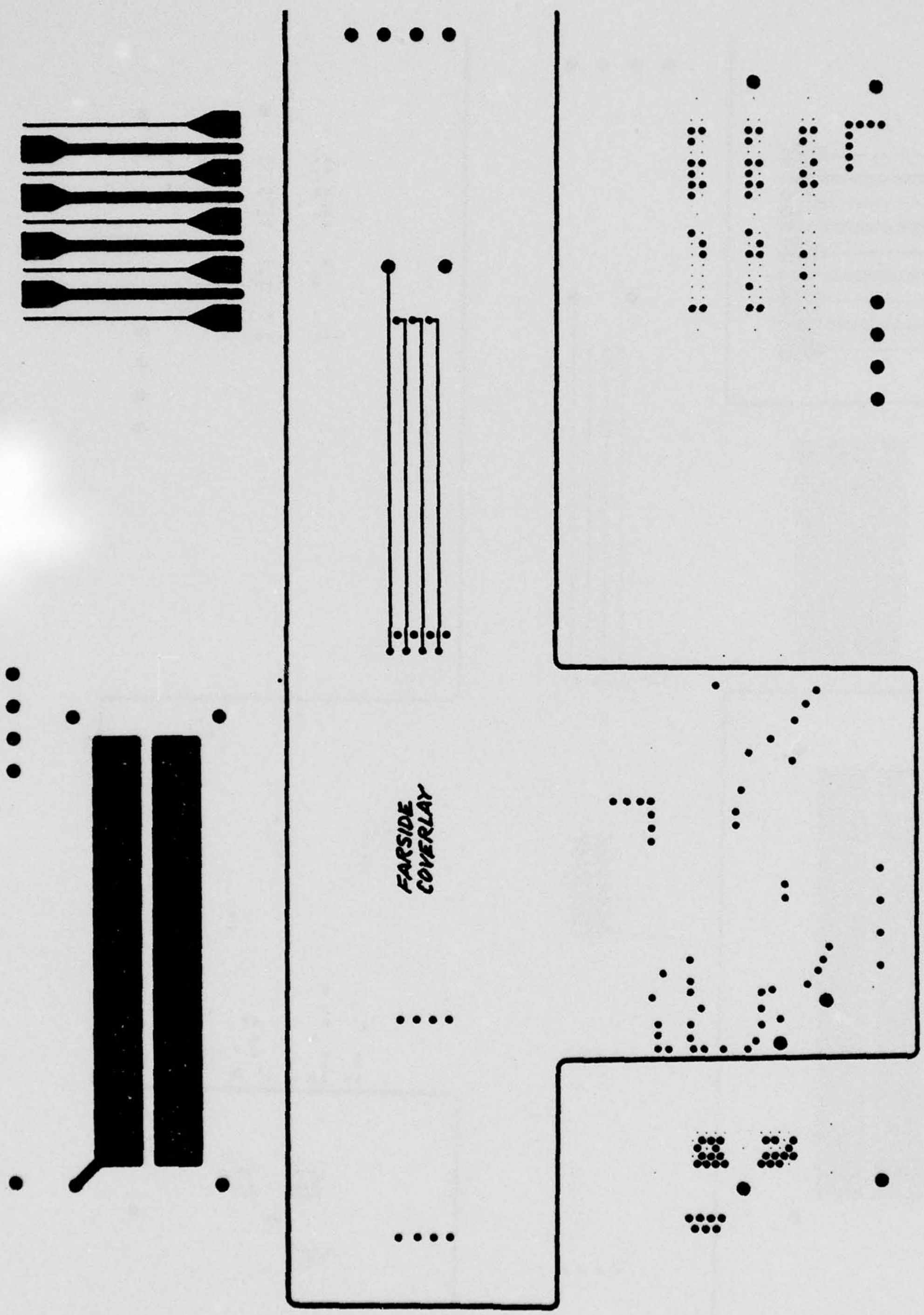


Figure 10.2.3.2. Farside Coverlay Pattern for Multilayer Pilot Lot FPW
(Coverlay View Through FPW With Adhesive Up)

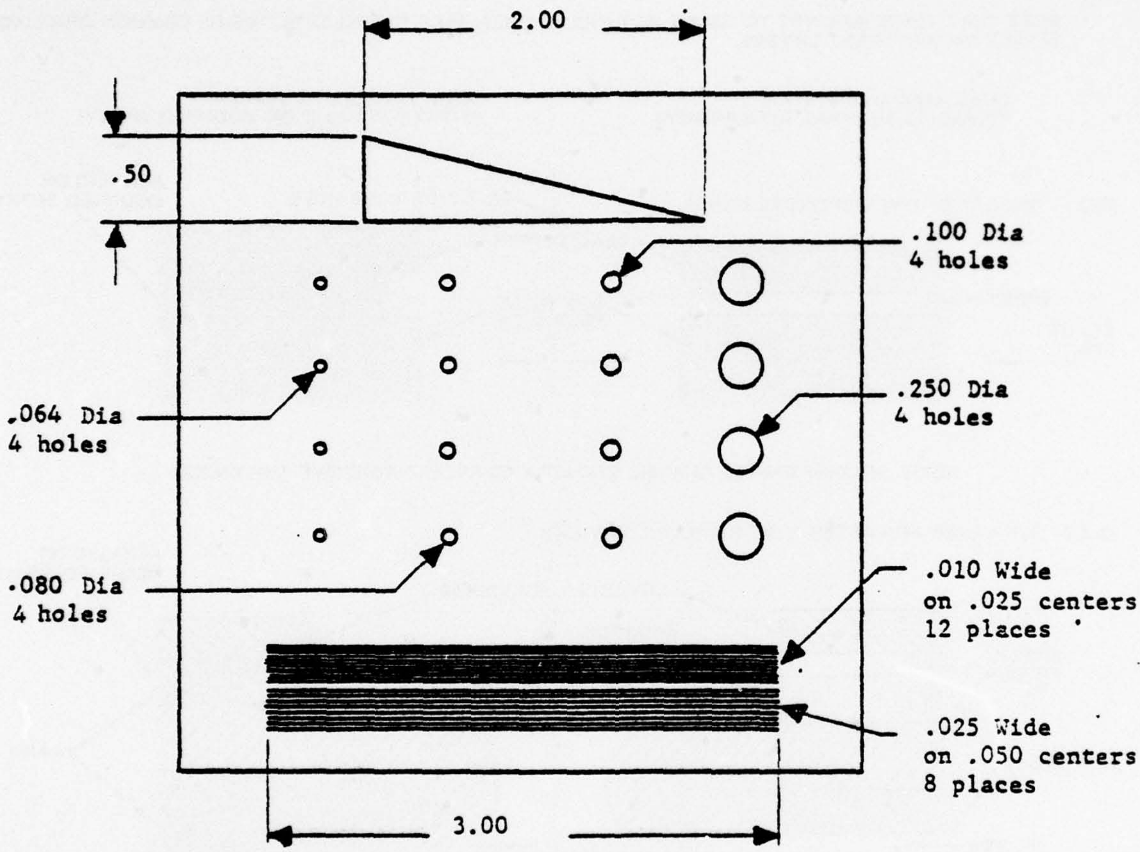


Figure 10.2.4. Adhesive Flow Test Pattern

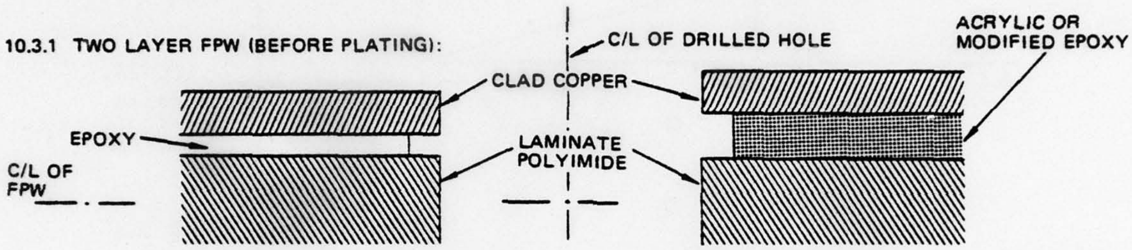
10.3 THROUGH HOLE CROSS SECTIONS:

NOTE THAT THESE ARE NOT TO SCALE, BUT INCLUDE SET-BACK REPRESENTATIVE OF COMMON DRILLING EFFECT ON DIFFERENT LAYERS.

DUAL ADHESIVE SYSTEM (PHENOLIC BUTYRAL WITH PRIMER)

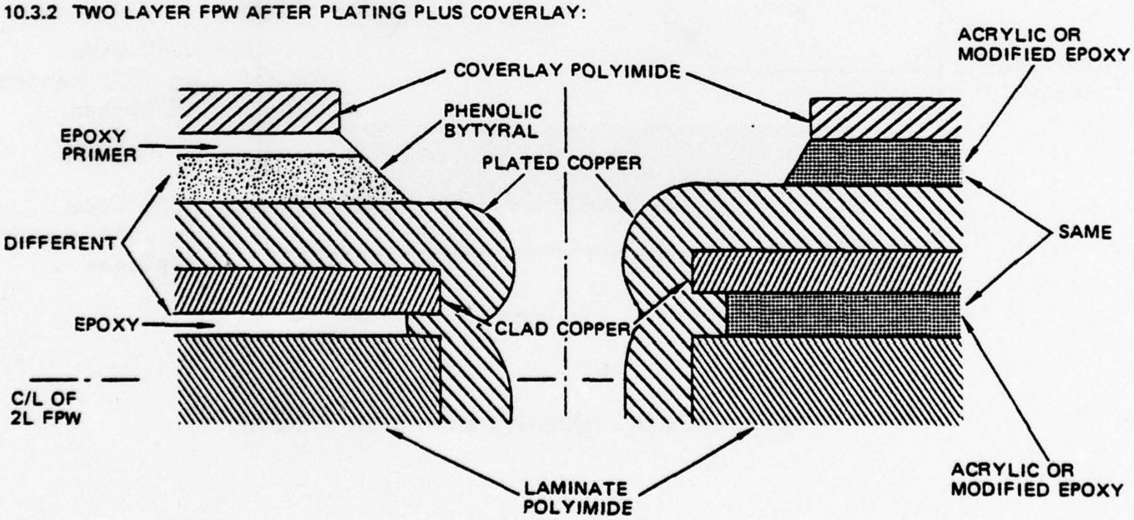
SINGLE ADHESIVE SYSTEM (EITHER ACRYLIC OR MODIFIED EPOXY)

10.3.1 TWO LAYER FPW (BEFORE PLATING):



NOTE: NO DIFFERENCE IN BASIC STRUCTURES EXCEPT ADHESIVE THICKNESS!

10.3.2 TWO LAYER FPW AFTER PLATING PLUS COVERLAY:



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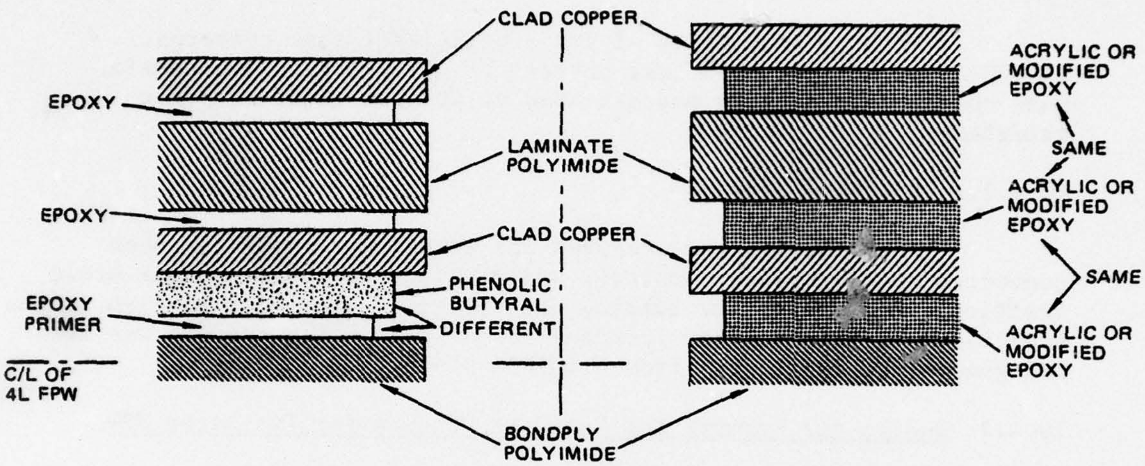
10.3.3 FOUR LAYER FPW (BEFORE PLATING):
NOTE THAT THIS INCLUDES PILOT LOT.

DUAL ADHESIVE SYSTEM
(PHENOLIC BUTYRAL WITH PRIMER)

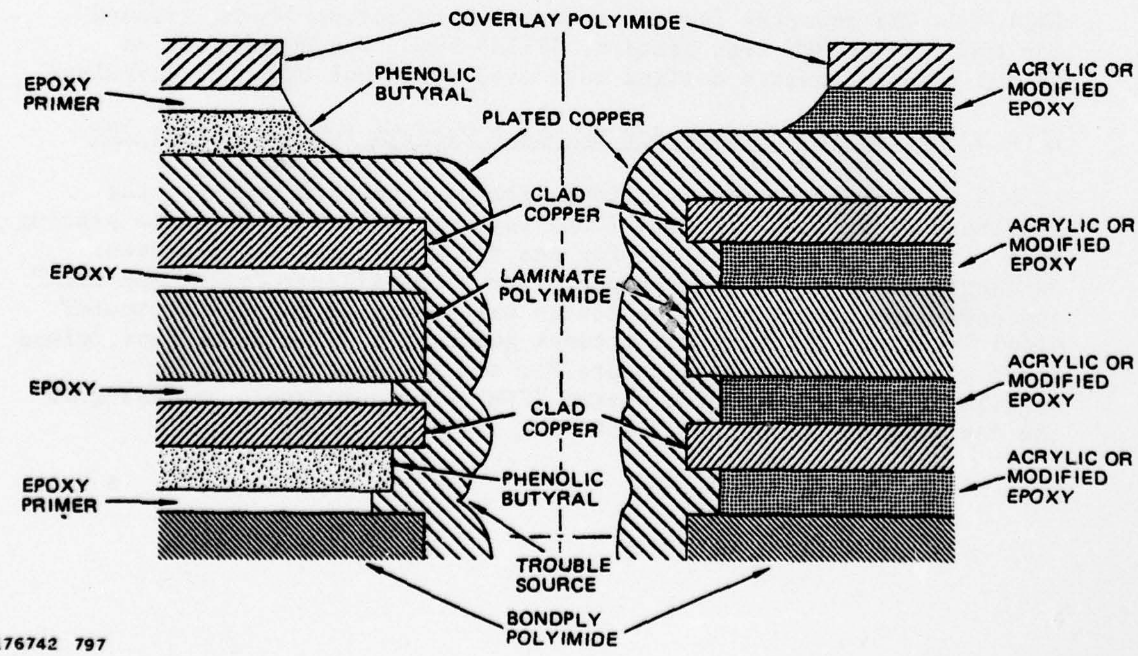
SINGLE ADHESIVE SYSTEM
(EITHER ACRYLIC OR MODIFIED EPOXY)



10.3.4 FOUR LAYER FPW (AFTER PLATING PLUS COVERLAY)

DUAL ADHESIVE SYSTEM

SINGLE ADHESIVE SYSTEM



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10.4 DESIGN AND PREPARATION OF TOOLING

10.4.1 Material Test Patterns

10.4.1.1 Single Layer Test Patterns

Working tool films of two single layer test patterns, SK 133-5020H and the peel test pattern of paragraph 10.1.6 herein, were obtained from photo masters used at GDP for tests of prior materials.

10.4.1.2 Adhesive Flow

A new design was prepared for adhesive flow tests, then converted to photographic masters and working tools by Computer Aided Drafting. A template for cutting out the triangular flow pattern in the adhesive materials and for locating the drilled holes therein was also designed, then fabricated from aluminum plate.

10.4.2 Design and Artwork for New Test Pattern for Two Layer FPW

10.4.2.1 A new two layer flexible printed wiring (FPW) test pattern (SP 133-5040) was designed to combine features of three previous test patterns, mostly derived from Institute of Printed Circuits (IPC) Technical Manuals. Artwork and a drill tape were prepared for this new design.

10.4.2.2 The coverlay (exterior circuit protection layer) pattern for the 2 layer FPW test pattern, SP 133-5040, was completed, as SP 133-5053. Separate designs were used for front and rear coverlay.

10.4.3 Design and Artwork for New Test Pattern for Multilayer FPW

10.4.3.1 The design for multilayer FPW test pattern combined the Institute of Printed Circuits (IPC) test patterns with an extra plating test pattern. The latter was for use for submitting an in-process AR (Analysis Request) test coupon prior to multilayer "print and etch" and coverlay lamination. The design was submitted for CAD (Computer Aided Drafting) plotting and artwork generation. The drill tape, glass photo plates, and planning sheets for the new test pattern for multilayer flexible printed wiring (FPW) were completed, and assigned the designation number SP 133-5047.

10.4.3.2 The coverlay patterns for front and rear for this multilayer FPW test pattern were designed as GDP drawing SP 133-5063.

10.4.3.3 Drill and cut-out templates for coverlay were prepared by exposing and developing the outer layer artwork pattern on photoresist on a phenolic board, then drilling those holes designated by the coverlay drawings with a bombsight drill (through a package of coverlay with the printed phenolic board taped firmly on top). A ruler and bandsaw provided for rectangular cut-outs, and an X-acto knife was used for trimming the coverlay to the drawing pattern. This technique was also used for two layer and pilot lot FPW.

10.4.4 <u>Design and Artwork for New Multilayer Pilot Lot Layout</u>

10.4.4.1 The pilot lot harness layout incorporated the most elaborate test patterns ever included on the same artwork with a Production flex harness at this plant. This permits extensive testing on the actual piece of material used for the pilot lot parts.

10.4.4.2 The Navy's Standard Missile -2 Head Control multilayer FPW, Part Number 3164124, was selected for the Acrylic Pilot Lot Inspection tests. Test coupons in accordance with MIL-P-50884 were added to the existing artwork, and the drill tapes and photo working tools were replaced accordingly, to allow full testing to MIL-P-50884.

10.4.4.3 This new artwork for the pilot lot was designated as SP 133-5067. It adds test patterns for plated through hole cross sections, peel strength, dielectric withstanding voltage, flexural fatigue, insulation resistance, solderability, terminal area bond strength, moisture resistance, thermal shock, and continuity to the existing L3164124 SM-2 four layer FPW artwork. It was plotted by Computer Aided Design. These test patterns permit the first article inspection of, and are from, MIL-P-50884 Type B, Class 2.

10.4.4.4 For the Pilot Lot part, SP 133-5067, glass plates and film sets were received after drilling of glass plates and installation of alignment pins. The drill tapes for two layer details, multilayer, and front and rear coverlay tooling alignment, plated through, and clearance holes were prepared.

10.4.4.5 For the Pilot Lot, the nearside and farside coverlay drawings were included as part (sheet 2 of 5) of the basic flex harness drawing SP 133-5067. Coverlay drill and cut-out templates were prepared as described above in paragraph 10.4.3.3.

11.0 YIELD AND COST ANALYSES

11.1 BASIS FOR ESTIMATION

11.1.1 Estimation Approach

Fabrication experience with the new materials and processes were used for yield and cost analysis inputs for comparison with current materials and processes in use at GDP. The yield and cost calculations are expressed in terms of comparison to existing processes. The multitude of differences in designs, production quantities, labor rates, facilities, productivity, and other factors within the industry make a precise dollar cost, and even a straight percentage yield figure difficult either to specify or to interpret correctly. The cost savings and yield estimates in this report are based on prediction of a 50% reduction in scrap losses in the multilayer fabrication steps, resulting in an overall net improvement of 22% in the final part yield.

11.1.2 Yield Basis

Estimations of the probable yield and cost effects of this project's proposed changes were included in the program plan. The results of the materials tests confirm the improvements in peel strength which will reduce losses during laminations, print and etch, plating, cleaning, handling, and assembly. Reduced adhesive flow saves some repair labor on some specific designs, but should not change the yield figures significantly. During fabrication of the two layer, four layer and pilot lot FPW in this program, as well as larger quantities of details, yields were excellent except for a few plating irregularities. All discrepancies detected were either abnormal or unrelated to the materials being fabricated. Except as noted in the test results, there was no scrap loss in the multilayer pilot lot fabrication. Therefore a high yield is expected from the acrylic materials with the complementary fabrication process in Production. The indicated yield has been reduced somewhat for this estimate over what was actually observed in development and pilot lot fabrication of this investigation, to allow for some typical production problems and to maintain a conservative goal. The real proof of our success awaits the results of a production program. Reduction of the scrap losses by half in multilayer operations is our predicted result, netting an overall average yield improvement of 22% for total part fabrication.

11.1.3 Type of Loss Which Is Not Reduced

For a cost yield analysis of multilayer FPW, it is essential to consider the factors affecting yield. Some of these are labor induced, such as an oversight in touchup resulting in an overetched circuitry line (etched line width narrower than specified). These are not directly affected by an improvement in materials which reduces delamination and handling losses.

11.1.4 Processing In Sequence

A major factor affecting yield is the number of processing sequences. For example, if two details are fabricated for a four layer FPW, and each has a 90% yield in "print and etch", the average yield for the two details is still 90%. But when the good details are laminated into a multilayer, and the multilayer undergoes "print and etch" a second time on the same panel, if its yield is 90% again, the remaining parts from one hundred started are now a product of the two sequential yields, or 0.90 x 0.90 x 100% = 81% yield. In addition, yields on multilayer "print and etch" should be lower in reality than on two layer, because the multilayer surface is no longer smooth and flat like the incoming clad laminate used for details. The same is true of all the other sequential operations, such as lamination, drilling, smear removal, plating, etc. Ten sequences at 90% yield each gives a rather low yield of $0.9^{10} = 0.35$ or 35%.

11.2 CALCULATION METHODS

11.2.1 Present Yields

A multilayer FPW is fabricated in three steps.

Step 1: Two layer "details" are fabricated (from raw materials), inspected and stocked.

Step 2: Multilayer "laminations" are fabricated (from two stock details and one bondply), inspected and stocked.

Step 3: Completed and trimmed FPW are fabricated (from one "lamination" and two coverlays), inspected, and stocked (for assembly).

11.2.1 Present Yields (Cont'd)

Yield data was accumulated for three months covering complete fabrication of one hundred accepted multilayer FPW for a representative production program. Yield for fabricating details from materials (step 1 above) was 0.70. Yield for fabricating FPW from accepted details was 0.59. This 0.59 yield includes both steps 2 and 3 above.

By definition: $\text{Yield} = \dfrac{\text{Accepted Parts}}{\text{Parts Started}}$

To obtain 100 accepted FPW parts per above formula at the 0.59 yield which applies to parts started as detail sets:

$$\text{Parts Started} = \frac{\text{100 Accepted Parts}}{\text{0.59 Yield}} = \text{170 Detail Sets}$$

To use available cost data later, the number of accepted "laminations", or step 2 above, is also needed. Since this data is not currently recorded, our best estimate is an equal number of scrap losses during step 2 and step 3. Then the number of laminations accepted, which is also the number of FPW started, will be halfway between the 170 started and the 100 accepted, which is 135.

The material sets required are calculated by the above formula as:

$$\frac{\text{170 Accepted Detail Sets}}{\text{0.70 Yield}} = \text{243 Material Sets}$$

The above may now be summarized as:

To obtain:	100 accepted FPW (present process),
start :	135 laminations, which are the number accepted from
starting :	170 detail sets, which are the number accepted from
starting :	243 material sets.

At 100% yield, of course, only 100 material sets would have been started to yield 100 accepted FPW. The "cost savings" at 100% yield would be the materials cost for the 143 extra sets actually started, plus the labor hours expended on those 143 material sets which were scrapped at different steps. The extra labor costs of material review, failure analysis and related documentation for the scrapped parts is not included in this analysis.

11.2.2 Predicted Yield Improvements For Acrylic Materials/Process

For the change of FPW fabrication from the present process to acrylic materials with the associated fabrication process, the results of the multilayer FPW fabrication, pilot lot fabrication, and tested improvements in peel strength indicate that scrap losses for detail fabrication (step 1 above) will be reduced by one . losses for the fabrication cycles of the more complicated multilayer lamination (step 2) and coverlay lamination (step 3) will each be cut in half. For the step 3 final FPW fabrication cycle, repeating the same formula and vaues above:

$$\text{Currently, } \frac{100 \text{ Parts Accepted}}{135 \text{ FPW Parts Started}} = \underline{0.74} \text{ Yield for step 3.}$$

When scrap losses are cut in half by use of the acrylic system, the yield will be 0.87 for step 3, a loss of 13 instead of 26 parts per hundred. For the "lamination" (step 2) by the same formulas:

$$\frac{135 \text{ Laminates Accepted}}{170 \text{ Detail Sets Started}} = \underline{0.794} \text{ Yield for step 2.}$$

When scrap losses are cut in half by use of the acrylic system, this yield will be 0.897 (rounded off to 0.90) for step 2.

When scrap losses are reduced one-third by change to acrylic for step 1, the original detail yield of 0.70 with the present material and method will increase to 0.80 for step 1 with the acrylic system.

The above yield values are consolidated below:

Step	Description	Present Yield	Yield After Change
1.	Details	0.70	0.80
2.	Laminations	0.79	0.90
3.	FPW	0.74	0.87

The same formulas above give the number of parts accepted and started for each step at the new yields after the recommended change to acrylic. Thus substituting into paragraph 11.2.1 above.

To obtain: 100 accepted FPW (acrylic material/process),
start: 115 laminations, which are accepted from
starting: 128 detail sets, which are accepted from
starting: 160 material sets.

11.2.3 Accumulated Data on Labor Hours Per Fabrication Step Versus Part Size for Multilayer FPW

Unit cost data provides a tabulation of costs for one year on multilayer FPW of a representative tactical missile system. It is important to note that this applies only to multilayer FPW which are in Engineering flight test hardware, fabricated in Production, and are in the forefront of the state-of-the-art for military multilayer FPW designs. A part fabricated on a 15 x 33 inch panel is used for an example. From the unit cost data, the average labor hours expended per accepted "dash number" gave the totals below for each of the three major fabrication steps previously described herein (paragraph 11.2.1)

Step 1	Details:	1.53	labor hours per accepted part
Step 2	Laminations:	8.04	labor hours per accepted part
Step 3	Completed FPW:	13.59	labor hours per accepted part

11.2.4 Quantity and Cost Basis for Savings Estimate Herein

The best available Production estimate for an extensive multilayer FPW program in the immediate future was calculated for a total quantity of 10,000 individual multilayer FPW. This seems the most reasonable basis for a production cost savings estimate. Actual costs will naturally vary according to size and complexity of the multilayer FPW, the year when produced, production rates per part number, material cost changes, etc.

11.2.5 Total Labor Hours Per Hundred Accepted FPW

Multiplying the number of accepted parts required for each step (from paragraph 11.2.1 above) by the labor hours per accepted part (from paragraph 11.2.3 above) gives the total hours labor expended at each step. Note that although material sets have a dollar cost, they are not included as a labor cost below.

Step	Description	Accepted Parts Required	Labor Hours/ Accepted Part	Total Hours per Step
1	Details	170	1.53	260
2	Laminations	135	8.04	1,085
3	FPW	100	13.59	1,359

Total = total labor hours per 100 accepted FPW by present methods = 2,704 hours

11.2.6 Breakdown to Labor Hours Per Part Started at Each Fabrication Step

For each step, the total hours shown above applies both to the number of parts accepted from that step, and to the number of parts started into that step, as follows:

(Accepted Parts) (Hours per Accepted Part) = Total Hours = (Parts Started) (Hours per Part Started).

Therefore, by simple algebra:

$$\text{(Labor Hours per Part Started)} = \frac{\text{(Total Hours)}}{\text{(Numbers of Parts Started)}}$$

For a given process, as yield changes, the numbers of parts started to produce 100 accepted parts will change, but the labor hours per part started will be more nearly constant, and is therefore needed to calculate cost changes as yield varies.

From the above formula:

Step	Description	Paragraph 11.2.5 Total Hours	Paragraph 11.2.1 Parts Started	Calculated Hours Per Part Started
1	Details	260	243	1.07
2	Lamination	1,085	170	6.38
3	FPW	1,359	135	10.07

11.2.7 Calculating Total Labor Hours At Different Yields

Note that the same formula can be used to calculate the total hours for any other number of parts started at each step. As the simplest example, at 100% yield, parts started would be 100 at each step, and the total hours would be simply as shown below in the fifth column.

11.2.7 Calculating Total Labor Hours At Different Yields (Cont'd)

TABLE XVIII TOTAL LABOR HOURS AT THREE DIFFERENT YIELD EXAMPLES

Tabulating calculations of total hours for these two examples and for the "actuals" for the present process:

Step	Description	Calculated Hours Per Part Started	At 100% Yield		Proposed Acrylic System		Present Phenolic Butyral	
			Parts Started	Total Hours	Parts Started Par. 11.2.2	Total Hours	Parts Started Par. 11.2.1	Total Hours
1	Details	1.07	100	107	160	171	243	260
2	Lamination	6.38	100	638	128	817	170	1,085
4.	FPW	10.07	100	1,007	115	1,158	135	1,359
Totals:				1,752		2,146		2,704

11.2.8 Calculating Labor Hours Cost Savings

The above shows a savings of (2,704-2,146) = 558 labor hours plus (243-160) = 83 sets of material per one hundred accepted multilayer FPW parts of this part number, if fabricated at the same point on the learning curve as the "actuals" tabulated for one year in 1975 and 1976. However, fabrication cost is on a learning curve of descending cost. Over an extended period, a percentage cost savings from a percentage yield improvement is more realistic. In the above example, the fractional saving between present and proposed systems is:

$$\frac{\text{558 hours saved}}{\text{2,704 hours spent}} = 0.21 \text{ times present method cost.}$$

This equals 21% labor cost savings for this FPW design.

11.3 EXTENDING CALCULATIONS TO OTHER MULTILAYER FPW

11.3.1 Calculations for Multilayer FPW From Actual Costs

This series of calculations can of course be used with the "actual hours labor" data for any other part number. Such data was tabulated for all of the four-layer FPW in one defense missile system, using the same values for "parts started" and "accepted parts required", but with the actual values for the labor hours for the accepted parts of each step (1,2 and 3). Repeating the above calculations gave a range of 19 to 26%, with an average of 22%, for the labor hours cost savings.

11.4 EXTENDING LABOR HOURS COST SAVINGS OVER PRODUCTION QUANTITIES

This 22% average labor hours cost savings was applied to a production cost estimate which is available for approximately ten thousand total FPW (900 FPW each of eleven designs). These calculations included large FPW fabricated on panels up to 24" x 33". The result was 111 labor hours cost savings average per hundred FPW over the 10,000 FPW production contract for the change to the acrylic materials and process.

11.5 TOTAL LABOR DOLLARS COST SAVINGS FOR TEN THOUSAND MULTILAYER FPW

At an estimated future full burden labor rate average for production of ten thousand multilayer FPW at \$25.00 per labor hour, times 111 labor hours per hundred FPW, times 100 (for the 10,000 ÷ 100 FPW) =

$$(\$25^{-})\ (111 \text{ hours})\ \left(\frac{10{,}000}{100}\right) = \underline{\$278{,}000}^{-} \text{ Total labor saving}$$

for 10,000 multilayer FPW using the acrylic materials and process.

11.6 MATERIAL COSTS SAVINGS ESTIMATE

11.6.1 Material Cost Approximation per Square Foot of Multilayer FPW at 100% Yield

Material costs are a direct function of the process panel area, if sizes are selected with equal compatibility for purchased material sizes (without excessive trim waste). Some material costs are approximated below. These will of course change with time and quantities.

11.6.1 Material Cost Approximation per Square Foot of Multilayer FPW at 100% Yield (Cont'd)

Material Cost Approximation per Sq. Ft. of MLF:

Double Clad Cu	\$7.36 x 2 =	\$14.72
Plating Chemicals	2.00 x 1 =	2.00
Bondply	4.88 x 1 =	4.88
Coverlay	4.00 x 2 =	8.00
Photoresist	1.00 x 6 =	6.00
Release Films and Rubber	1.00 x 2 =	2.00
Total (at 100% yield):		\$37.60

Divide by (% yield/100):

Examples of material costs:

At 50% yield = \$75.20/sq. ft.

At 75% yield = \$50.10/sq. ft.

11.6.2 Material Cost Breakdown Into FPW Fabrication Steps.

11.6.2.1 Step One

Step 1 (details) uses 2 details, each with photoresist on both sides, without plating or laminations. This costs:

2 double clad material	= 2 x \$7.36 =	\$14.72
4 photoresist layers	= 4 x \$1.00 =	4.00
Total material cost/sq. ft. for Step 1 =		\$18.72

11.6.2.2 Step Two

Step 2 (laminations) uses one bondply for one lamination, plus multilayer through hole plating once, plus photoresist on two sides of one part. This costs:

11.6.2.2 Step Two (Cont'd)

1 bondply at	$4.88	=	$4.88
1 lamination at	1.00	=	1.00
1 plating chemicals at	2.00	=	2.00
2 photoresist layers at	1.00	=	2.00
Total material costs/Sq. Ft.		=	$9.88 for Step 2.

11.6.2.3 Step Three

Step 3 was two coverlays (one per side) in one lamination, without "print and etch" and with negligible plating costs (immersion tin). This costs:

2 coverlay at	$4.00	=	$8.00
1 lamination at	$1.00	=	$1.00
Total material costs/Sq.Ft.		=	$9.00 for Step 3.

11.6.3 Material Cost Savings for Change to Acrylic Material/Process

11.6.3.1 Material Cost Per 100 Parts Started

The material cost for 100 parts started at each step of any process equals:

(Material Cost per Square Foot for That Step) (Square Feet per 100 FPW Started).

11.6.3.1 Material Cost Per 100 Parts Started (Cont'd)

The total square feet of area per side for the multilayer fabrication panels to start one hundred average multilayer FPW were calculated from the program used for the cost data base herein. Without providing any correction for panel trim waste, the total square feet of area of multilayer laminates for starting 100 average multilayer FPW is 329 square feet. Since these calculations ignore trim waste, are for a specific area value (329 square feet), and assume that material costs per square foot are equivalent, the costs for each step are constants times the varying number of parts started at that step for different processes. The above material costs/sq.ft. for each step are multiplied by the one calculated average area sq. ft. of panel per 100 multilayer FPW, to give the material costs per 100 average parts started.

Material Costs/Sq. Ft. For Step Shown		Sq. Ft. of Panel per 100 FPW		Material Cost Per 100 Average Parts Started	
$ 18.72	x	329	=	$6,120⁻	for Step 1
9.88	x	329	=	$3,250⁻	for Step 2
9.00	x	329	=	$2,960⁻	for Step 3

11.6.3.2 Material Savings Per 100 FPW Accepted

The total cost per 100 completed FPW "parts accepted" for any process will be the sum of the material costs for each of the three steps therein. The material costs for each will be the product of the above calculated "constant" (material cost per part started for that step) times the number of "parts started" at that step, for that process, which are the variable quantities calculated previously herein. Since the material costs at each step are each a constant times a variable "parts started", the cost differences at each step for any process are simply that constant times the difference in quantity of parts started in that step.

11.6.3.2 Material Savings Per 100 FPW Accepted (Cont'd)

The first five columns below are data from above.

Per 100 Parts Accepted

Step	Parts Started for Present Process		Parts Started for Acrylic Process		Savings in Parts Started		Mat'l. Cost Per Part Started	Mat'l. Savings Per step per 100 FPW Accepted
1	243	-	160	=	83.	x	\$61.20	\$5,080
2	170	-	128	=	42,	x	32.50	1,365
3	135	-	115	=	20,	x	29.60	592
Parts Completed	100		100		-			
Totals	-		-		-		\$ 123.30	\$7,037

The above total material cost per part started (\$123-) is the average material cost per multilayer FPW, even at 100% yield, so material is obviously a significant expense of FPW fabrication, especially for production quantities. The last total above, \$7,037¯, is the material savings estimated for fabrication of 100 accepted average multilayer FPW under last year's actual conditions if the acrylic material and process had been available and were used then.

11.6.4 Total Material Cost Savings Per Ten Thousand FPW in Production

The material cost savings per FPW for the change to the acrylic materials and process will of course be less than above for future production run quantities, due to normal learning curve improvements which would have been expected even with the present process. It will probably be increased by inflation as material costs increase, though this effect is not included in the material savings estimate. We estimate that the scrap losses for a production run of ten thousand multilayer FPW would be cut to half of the preceding actual data results due to learning curve improvements even without the acrylic material and process. Then the material cost savings with acrylic would likewise be halved for the 10,000 multilayer FPW run, to a value of:

$$\left(\frac{\$7{,}037}{2}\right)\frac{10{,}000}{100} = \$352{,}000^{-}$$ material cost savings per ten

thousand multilayer FPW (or \$35¯ average material savings per FPW).

11.7 OVERALL COST SAVINGS

11.7.1 For Multilayer FPW

A labor hourly rate is needed to convert labor savings into dollars for combination with material savings. The full burden rate was used, and the 1980 estimate of $25/hour was selected for round numbers as a likely potential median within the 10,000 multilayer FPW production period. The estimated cost savings per ten thousand production multilayer FPW for materials and labor can be combined as 11,100 labor hours, times the average (full burden 1980 estimate) rate of $25 per labor hour, equals $278,000 total labor cost, plus $352,000 total material cost savings, equals:

$630,000 total savings per ten thousand multilayer FPW

(or $63 average total cost savings per FPW) from the change to acrylic materials and process.

11.7.2 Other Benefits Beyond Material and Labor Cost

The improvement in yield will provide substantial benefits in reducing many overhead costs for the extra inspection, quality control, material review, and documentation of scrap results. These are especially significant in areas such as multilayer flexible printed wiring where yields tend to be low due to operations pushing the state-of-the-art for defense advantages.

11.7.3 Improved Assembly and Reliability

Although the record for FPW in missiles has been good, an improvement in reliability and a reduction in repairs and losses during assembly and field use, and an increase in longevity in service, are generally conceded as normal gains in the printed wiring industry when yield improves at the fabrication level. Since the value of avoiding even one failure of a large missile in either test or use would exceed the cost of this entire development program for adopting acrylic materials, this extra reliability becomes an obvious though difficult-to-measure additional cost savings.

11.7.4 Process Simplification Cost Savings

As described in Appendix II and III, there was a major simplification achieved by this project in reducing the number of tanks, solutions and operations required for the chromic acid smear removal process, in addition to making it work at all for acrylic

11.7.4 Process Simplification Cost Savings (Cont'd)

materials, and in improving the process yield for through hole plating. This process simplification might be roughly estimated as five percent of the total multilayer FPW fabrication labor hours, and as such is quite significant. However, the plasma smear removal is an even greater improvement in both yield and simplification, so that the improved wet chemical method is not planned to ever be adopted here for production (though it probably will be used elsewhere). Therefore no processing time savings are included in this estimate. They are instead justifiably attributed to the plasma smear removal process, which was a separate development, even though promptly adopted by this project to facilitate the change to acrylic materials. On page xxi,the simple plasma process (from the multilayer FPW drilling up to the electroless plating process) is compared to the prior chromic acid smear removal process (with the precautionary rinses necessary to insure good results by avoiding chromium poisoning). The plasma chamber step replaces twenty seven steps of a wet chemical process line with its associated solution control, waste disposal, fume ventilation, safety, water, power, and plating line contamination problems. The chromic acid was the most difficult problem in operation of an automated plating line for FPW, and its elimination greatly simplifies both process and waste control.

11.7.5 Navy Break-Even Point

Considering only those cost savings for the changes to the acrylic materials/process in labor hours plus materials for multilayer FPW, the contract cost of this project will be recovered when the number of accepted multilayer FPW on the model program equals this contract's cost of $113,000 divided by the average cost savings per FPW of $63 , or after only 1800 multilayer FPW. Since it is anticipated that this material and suitable variations of the basic fabrication process described in this report will become a principal mode of production for multilayer flexible printed circuitry in defense systems, the total cost savings to be realized by the government and various contractors will be many times that projected for the example presented here.

12.0 SUMMARY

It is clear that this project has been successful. A change to the acrylic material has been recommended by this project team for printed wiring harnesses fabricated at GENERAL DYNAMICS Pomona, and there is considerable confidence that such a change will be approved this year. The project offices are expected to approve the changeover on all continuing programs in order to improve their yields, improve product reliability, and reduce their program costs.

Further development to extend these capabilities to flex-rigid hybrids, and for continuing cost saving yield improvements, is recommended for future programs. This program has provided a valuable foundation for further qualification and test operations, and for further reliability improvements.

The original overall "Test Plan", the "Requirements and Test Methods" for four categories (materials, two-layer FPW, four-layer FPW, and multilayer FPW pilot lot), and the "Test Procedures" for the same four groups have been distributed. All artwork and tooling for the program has been completed and used successfully. Five test reports have been issued.

The parallel effort on plasma smear removal was folded into the acrylic material changeover as a combined change for maximum efficiency in Production assimilation of these cost reductions. The estimated cost savings of $700.00 per ship set of a representative tactical missile system such as the Standard Missile - 2 pilot line program indicates the importance of these project results. In addition, the reliability and schedule improvements should eventually prove to be as important as the bare reduction in dollar cost.

APPENDIX I

Fast Evaluation of Etching Results and Control of Chromic Acid Etchant

Test panels were prepared cheaply by etching double-clad polymide-acrylic panels (partly masked with plater's tape) in this sequence: the copper from part of one side, the acrylic adhesive from the exposed area, and then the copper from part of the other side. This provided sheets with exposed surfaces of copper, acrylic, and polyimide. Etching tests of small strips cut from such sheets prior to part processing, followed by observation under a microscope after a quick water rinse and air dry, provides a check of any undesirable copper surface etch, acrylic surface effects, induced delamination effects, and polyimide surface effects, as well as permitting a rough estimate of etch rates. This test was refined with use, and after selection of a specific etchant system, daily monitoring before use can be performed without even requiring the microscope. After a one minute etch, quick flowing water rinse, and pressure air drying, the acrylic surface is "whitish" to the naked eye if excessive dilution, inadequate heat, or excessive contamination have inactivated the chromic acid etchant. This two minute "quality control" test performed by the operator is excellent insurance against a failure which would normally not be observed until after the AR coupon is cross-sectioned, mounted, and studied microscopically. The "whitish surface" is hydrolyzed and/or redeposited material which may absorb contaminants or react adversely in later processing. The "clean" translucent plastic surface indicates a genuine etching action which removes at least part of the modified surfaces.

GENERAL DYNAMICS
Pomona Division

APPENDIX II

February 27, 1976

ELECTROLESS COPPER LINE SIMPLIFICATION

By

Stephen A. Hays

GENERAL DYNAMICS

Pomona, California

Abstract

This explains and resolves the plating industry's recurring bugaboo of "chromium poisoning" of palladium-catalyzed electroless copper plating lines.

This also provides the industry's first known capabilities for wet chemical etching for smear removal in drilled holes of acrylic-adhesive laminates, and for satisfactory copper plating of through holes after chromic acid etching of such laminates, which are used for flexible printed wiring.

From the present multilayer through hole plating line, this development eliminates the hot alkaline etchant, hot water rinse, first hydrochloric acid dip, ammonium persulfate solution, and strong sulfuric acid dip (a total of five solutions plus associated rinse tanks). Several solutions are changed, but only one extra, oven-drying step is added.

Introduction

The following statements are an outline of what, in the speaker's personal opinion, constitute the major discoveries which combined to yield a successful process for through hole plating of multilayer flexible printed wiring which has been laminated from copper and polyimide with acrylic adhesives.

Although these preliminary laboratory discoveries are the combined results of two research programs at General Dynamics Pomona Division, sponsored respectively by the U.S. Navy (Contract N00123-76-C-0138) and by General Dynamics (IRAD P-043), this presentation contains only the author's opinions, rather than any Navy or Corporation decisions.

These are subdivided into three groups. The first group are general suggestions for the printed circuits industry, concerning hole drilling, hole wall inspection, process control test strips, and tensile peel tests on finished part trim area. The second group resolves the plating industry's recurring bugaboo of "chromium poisoning" of electroless copper plating lines, and should therefore be of general interest wherever palladium catalyst activation is used for electroless copper plating of through holes in the electronics printed circuits industry. The third group is more specifically applicable to the smear removal and plating of through holes in multilayer laminates which are fabricated with acrylic adhesives (such as DuPont's Pyralux copper-polyimide laminates) for flexible printed wiring. Flexible printed wiring provides the wiring harnesses or cables which replace bundles of individual wires where high interconnection density, reproducibility, and reliability are critical. Such "flex harnesses" are mostly found in aerospace, missile, guidance, and defense industries.

General Suggestions For The Printed Circuits Industry

Drilling results are improved if the product of drill speed times drill diameter divided by feed rate, or (RPM X DIA.) ÷ IPM, is kept reasonably constant, at a value selected for the specific stack of materials being drilled. This essentially creates a constant angle of attack of the cutting edge through the material at the periphery of the hole, instead of providing the constant depth of cut per revolution sometimes recommended by others.

Drilling, smear removal (or etchback) and plating results should all be controlled by viewing hole walls through a microscope (at 15 to 60 X magnification) at an angle with back lighting. This can be reasonably efficient if properly set up with a tilted microscope suspended over a light table which provides free movement of large panels, so that focusing is achieved simply by sliding the parts.

Double clad copper-polyimide laminate (which includes whatever adhesive is being used) can provide excellent control test panels after selective (masked) etching through one strip of copper, then through all of the exposed adhesive, then through another copper strip. This leaves exposed strips of copper, cured adhesive, and polyimide. Small strips cut from these panels and processed directly ahead of and/or with production parts can cheaply provide a quality and process control of the entire line, which is particularly useful to show effects of smear removal, efficiency of catalyzation, electroless plating, and adhesion to three different materials.

Tensile peel tests of test pattern strips in the trim area, which match the narrowest circuitry artwork on the parts, after parts are completed and trimmed (including cover sheets and immersion tin) would provide significant comparisons of part quality, including effects of overetching, of original material quality, and of all processing operations.

Chromium Poisoning of Electroless Copper Plating Lines

This second group of opinions resolves the plating industry's recurring bugaboo of "chromium poisoning" of palladium-catalyzed electroless copper plating lines for plated through holes of electronics printed circuitry.

The printed circuits industry has long suffered from the fleeting ghosts of "chromium poisoning" of electroless copper plating lines, with the resultant problems of plating voids and plating adhesion failures. As a result, some plating establishments even insist that chromium solutions (such as epoxyglass smear removal, chromium plating, and chromate surface treatment solutions) be kept in a separate area away from the electroless copper plating lines. This development does not change the wastewater disposal problems of chromium compounds, but it should eliminate the other electroless plating line chromium contamination problems.

Electroless copper plating lines which use palladium catalyst activation are easily poisoned by traces of hexavalent chromium. The effect of chromate in modifying the deposition of palladium catalyst onto both organic and metallic surfaces in turn leads to plating voids on the non-metallic surfaces and/or poor plating adhesion on the metallic surfaces. Avoiding physical entrapment of chromates in crevices of or between the parts and racks requires extreme precautions of vigorous and repetitious rinsing and reracking. After applying these expensive precautions, it finally became obvious that further chromium poisoning still remains due to surface reactions with specific materials. These reactions are much stronger with acrylics (and also with 3M #1280 plating tape, and Scotchbrite cleaning pads) than with polyimides plus phenolic butyral, and are relatively minor with epoxies and epoxyglass. Therefore chromium poisoning is much less serious (and frequently unnoticed) with ordinary epoxyglass printed wiring boards, even when chromic acid smear removal is used. In any two layer printed wiring board plant where there are no chromate solutions nearby, chromium poisoning is unlikely. However, once the processing line is contaminated with chromates, it may cause plating voids and plating "peelers" even on two layer parts processed therein. The extreme tendency of acrylics

to transfer chromium both necessitated resolution of the chromium poisoning, and helped resolve that problem by making improvements more measurable.

Eliminating ammonium persulfate from the electroless line avoids reoxidation of trivalent chromium. Even though both sodium bisulfite and hydrochloric acid solutions were used after the chromic acid smear removal to reduce residual chromates, and extreme precautions had been taken to minimize entrapped chromates, typical chromium poisoning effects were still observed. It seems illogical that the remaining trace amounts of trivalent chromium could have this much effect. This led to the author's conclusion that the ammonium persulfate dip, long a common part of most electroless copper plating lines, was reoxidizing enough trivalent chromium to hexavalent chromium to poison the palladium catalyst step. The obvious solution is to eliminate the ammonium persulfate bath, as well as the following rinse. The ten percent sulfuric acid solution and its following rinse are usually used to clean up the surface residues from the persulfate etching of the copper surface, so these can also be eliminated. Besides improving the results, these eliminations appreciably simplify both the process and the process line.

A concentrated solution of copper chloride in hydrochloric acid can replace the ammonium persulfate if a "copper etchant" is still desired for chemical deburring or for modifying the surface. The oxidizing potential of copper chloride is sufficient to etch copper, but too low to oxidize the trivalent chromium. This solution was used successfully in the laboratory, but abandoned as unnecessary for multilayer printed wiring products (either flex harnesses or boards), which have already been subjected to the chromic acid etchant.

Use of concentrated hydrochloric acid (full Technical strength as normally purchased) directly before the palladium catalyst (without rinse) avoids chromium poisoning. An acid dip without rinse normally precedes the "activator" or Palladium catalyst solution in electroless copper lines, partly to avoid diluting the catalyst with water from "drag-out". This was formerly a 25 volume % hydrochloric acid solution, although sodium chloride (salt) is frequently substituted for part of the hydrochloric acid to reduce the fume control problems. However, the reduction of chromate by chloride ion is a reaction extremely dependent on the concentration of hydrogen ion, which is the acidity, generally measured as pH. The reaction is basically:

$$CrO_3 + 3\ Cl^- + 6\ H^+ \rightleftharpoons Cr^{+3} + 3/2\ Cl_2 + 3H_2O$$

This means that in the simplified equilibrium constants, the hydrogen ion concentration is effective to roughly the sixth power, compared to the chloride ion in the third power, and the chromic acid and chromium ions both in only the first power. Therefore a decrease of only one pH unit should reduce the residual chromic acid concentration by a millionfold (as a rough theoretical approximation). This is probably not quite true, but it does emphasize the primary importance of the hydrogen ion concentration, and the secondary importance of the chloride ion concentration, as a reducing agent for hexavalent chromium directly preceding the palladium catalyst. Since increasing the hydrochloric acid concentration increases both the hydrogen and the chloride concentrations, this is most effective.

For a laboratory pilot line, the use of concentrated hydrochloric acid preceding the catalyst, combined with elimination of the ammonium persulfate and sulfuric acid, provided sufficient elimination of chromium poisoning for good electroless plating of through holes, even when the hot water rinses, sodium bisulfite reducing solution, 25% hydrochloric acid dip, and a multitude of extra rinsing and reracking operations were eliminated, providing a greatly simplified process line. Thorough rinsing and racking care to avoid entrapped chromate solution is still necessary, of course. However, fume control problems make concentrated hydrochloric acid difficult or impractical for Production use. Therefore an alternate method was sought. Prior to resolution of the chromium poisoning problems, experimentation had revealed that five minute immersions in hot, dilute solutions of sodium hypophosphite, and room temperature, concentrated (10-20%) solutions of sodium bisulfite were each beneficial, without damaging the materials common in our printed wiring products. For energy conservation, the sodium bisulfite at room temperature was selected. When adjusted to pH 2, the sodium bisulfite and a rinse can be used preceding the common 25 volume % hydrochloric acid in lieu of the single concentrated (100 volume %) hydrochloric acid solution. Because of the importance of the hydrogen concentration, as already described, substitution of common salt for part of the 25% hydrochloric acid is not recommended without extensive testing. Although use of dilute sulfuric acid (for lowering the pH of sodium bisulfite to pH2) adds to the concentration of the sulfate reaction product, so that it is not quite as powerful as a reducing agent, this is probably justified to keep the total bisulfite composition more simple for control.

Elimination of the chromium poisoning problem does not require modification of the remaining electroless line after the hydrochloric acid preceding the catalyst. These steps depend more upon the materials being plated, and any line currently successful for given materials should remain so after these recommended process changes are made.

GENERAL DYNAMICS
Pomona Division

S. A. Hays
2 March 1976

Through Hole Smear Removal and Plating of Multilayer Copper-Acrylic-Polyimide Laminates

Plating of two layer flex harnesses made with acrylic adhesive laminates is no special problem. Although some multilayer plated through hole printed wiring products using acrylic adhesives are reported to exist in the industry, no prior satisfactory wet chemical smear removal process has been available for laminates using acrylic adhesives. Superior drilling techniques and physical cleaning methods such as liquid honing are reportedly necessary. The following observations are still based only on laboratory pilot plant studies and fabrication of test patterns for which testing is incomplete.

Figure I compares photomicrographic cross sections of good and bad plated through holes in four layer flexible printed wiring made from copper-polyimide laminates with phenolic butyral epoxy adhesives. Figure II shows some of the typical difficulties encountered in plating laminates with acrylic adhesives using prior processes and solutions. Figure III shows plating which is considered satisfactory on a plated through hole in a copper-acrylic-polyimide laminate, plus the plating on the sheared edge of the same panel to show what might be expected as the "worst-case" if a hole were drilled very poorly.

In the author's opinion, the photomicrographic cross sections to date indicate a high probability that resolution of the original problem of finding a wet chemical smear removal process for acrylic laminates has been achieved. The information herein should provide sufficient data for confirmation of the process by others desiring its use. In addition to the resolution of the chromium poisoning problem already discussed, which was especially severe for acrylic materials, the following are the major discoveries considered helpful in improving the through hole plating of flexible printed wiring with acrylic adhesives.

The "smear" in plated through holes is generally from entry and backup materials, and from softer or adhesive materials which spread, especially after local overheating from drilling creates further softening or charring. The toughness and high thermal resistance of polyimide greatly decreases any change of polyimide "smear" on metal surfaces, although "slivers" of polyimide are included in some drill debris, or may still be attached. The industry consensus seems to agree that there is negligible "polyimide smear" after reasonably good drilling. Therefore an adequate smear removal process should not require etching of the polyimide, even though more uniform hole walls could be provided with carefully controlled preferential etching of polyimide. The preliminary strong alkaline etchant (Isoprep 177 from Allied-Kelite) which is commonly used to soften and hydrolyze polyimide

before chromic acid etching, was eliminated to avoid excessive swelling of the acrylic adhesives. This not only eliminates a heated solution, which required considerable thermal and chemical control, plus rinsing operations and care in processing, but it also greatly increases reproducibility, because careful balance of alkaline and acid etching was previously required to avoid wide variation in results.

Most prior chromic acid etchants leave a whitish film residue which is visible on the acrylic surfaces after rinsing and drying. Avoiding this residual film by selection and control of the chromic acid etchant both reduces plating problems and serves as an economical etchant control.

Adding about 25 volume % of phosphoric acid to concentrated chromic acid provides a true acrylic etchant (rather than simply softening and swelling the acrylic) with lower chromic acid concentration and less precipitation problems than were encountered earlier. Water content is quite critical for chromic acid etchants.

Higher chromic etchant temperature provides cleaner etch with less acrylic residue. Temperatures from 160 to 220^{o}F. appeared suitable, and some variation of temperature to control etch rate as composition varies may be useful.

A multitude of alkaline, organic, and strong acid solutions are detrimental to the acrylic adhesives after chromic acid etch, in increasing their tendency to swell and exude "ruffles" during electroless plating. Hydrochloric, hydrofluoric, and bisulfite are notable acidic exceptions. Therefore there are no problems in using the bisulfite and hydrochloric acid solutions previously described to avoid chromium poisoning. Hydrofluoric acid (about 15 volume %) did not seem harmful, and even appeared slightly beneficial for adhesion of plating to acrylic adhesives, but it is only needed for fiberglass reinforced materials such as rigid multilayer boards.

Even the Shipley Conditioner 1160, which was proven so useful in 1974 for improving plating adhesion to polyimide, and revealed no damage to polyimide, epoxy, and phenolic butyral after six days immersion, increased the swelling of acrylic. However, a faster-acting alkaline-organic solution (Dynastrip 99A) to promote adhesion to polyimide was found by Dynachem Corporation and R. W. Aubert of General Dynamics, Pomona, who recommended its trial for acrylic-polyimide laminates. It also caused swelling and delamination of acrylic adhesives, but when used briefly after chromic etch and rinse, and combined with an oven drying operation prior to electroless copper plating, it improves plating adhesion to polyimide without excessive swelling of the acrylic.

Some proprietary catalysts increased swelling of acrylic, but a satisfactory "modified proprietary" catalyst solution was developed at General Dynamics using Shipley products.

Acrylic swelling was increased unfavorably by Shipley's Accelerator 19, but Dynachem's Conditioner 101 worked satisfactorily. This is used between oven drying and electroless copper.

A circulating air oven drying operation (about 160°F. for from ten minutes to four hours) after the "conditioning" and rinsing following catalyzation, improved the adhesion of electroless copper to polyimide, thereby reducing the chance of plating voids. This step might substitute for a "holding tank" to adjust process flow, and it provides an opportunity for in-process examination of a sample part to insure success of the drilling, smear removal, and electroless preparation operations. It may not be a requirement for Production, however, after other steps are optimized.

The Dynachem Conditioner 101 in the laboratory tests was used (with rinses) both before and after baking, and also after electroless plating. In normal production, it should not be needed after electroless plating, if another acid dip is already available preceding the copper electroplating tank.

The common electroless copper solutions, both proprietary and historical, also tend to increase swelling and exudation of acrylic adhesives after chromic acid etching. This means first that a slow-acting, "depleted" electroless copper solution, by increasing the immersion time before enough electroless copper film forms to provide some surface protection, will be more hazardous to acrylics than an active, carefully controlled bath. Lower pH probably helps somewhat, though this is offset by the resulting reduction in plating rate, and most electroless copper baths are in a similar and rather narrow pH range. The organic additives present must also have varying effects. The Dynaplate 240 A + B (Dynachem) electroless copper was considerably more successful for acrylics than was the Shipley 328Q electroless copper. Note that these tests have no bearing on the relative utility of any of the proprietary products listed for plating of non-acrylic materials.

In earlier experiments in this study, the slightly acidic electroless nickel solutions, primarily because of their lower pH, provided the first successful electroless plating of multilayer acrylics. The electroless nickel baths were later abandoned when success was also achieved with electroless copper, in order to avoid the high temperature (heating) requirements of electroless nickel baths, to avoid any

possible specification conflicts from the presence of nickel, and possibly because electroless nickel is generally more brittle. However, the writer believes that some electroless nickel plating may still have promise for further future applications to through hole plating in electronics.

When the process is marginal, there are substantial differences in the effects on both acrylic and polyimide between the planar surfaces, among drilled versus sheared versus punched holes, between different degrees of adhesive cure obvious on multilayer parts due to multiple lamination cycles, and between straight exposed edges and drilled holes (due to different stress relief and swelling patterns). These minor variations become indistinct when sufficient safety margin is provided in the process. That justifies extra effort to avoid excessive "productionizing" of the process to minimum times and control, where yield and reliability decrease.

Although many minor modifications of the total smear removal and plating sequence are preferred by different plants, this process greatly reduces the complexity of rinsing and reracking requirements generally used to minimize "chromium poisoning" problems. For example, at our plant it also eliminates a hot water rinse, the reracking of parts, the multiple spray rinses before and after many of the early process steps, and all of the rinses accompanying the various solutions which were eliminated (including the hot alkaline etchant, first hydrochloric acid dip, ammonium persulfate, and sulfuric acid). Of course, counterflow spray rinse operations are still useful where available to increase efficiency and to reduce water consumption, discharge, recycling, and pumping costs. Deionized rinse water is not required, but is of course recommended for solution makeup and for replacing evaporation. It is also desirable as a second, final rinse after the Conditioner 101, where it would then immediately precede both the oven dry and the electroless plating. It is not really needed before electroplating when that is preceded by an acid dip without rinse. It is not needed directly after plating, because a later step is the vigorous cleaning in preparation for photoresist application.

Comparison of Processes for Smear Removal and Electroless Plating

Since this process for plated through holes in copper-acrylic-polyimide laminates now appears successful per hole cross sections, a comparison of this total process with the comparable pilot plant process (as developed by the same person) for the present copper-phenolic butyral-epoxy-polyimide laminates seems fair and is presented next. When operations may be easily repeated with the same equipment, the operation number is simply repeated. For substitutions of related operations, "A" refers to the older process (on the left below),

and "B" refers to the newer process involving acrylic materials. Blank lines denote operations not required for both processes. "SAME" in the right column means that the operation is the same as shown in the adjacent left column. Note that the new process also produced good results both with the older materials (phenolic butyral and epoxy adhesives), and with epoxyglass materials if a hydrofluoric acid dip is added. The comparison chart is attached.

Summary

Chromium poisoning of electroless copper plating lines may be avoided by thorough rinsing after chromic acid smear removal, elimination of ammonium persulfate, and use of concentrated hydrochloric acid immediately preceding the palladium catalyst. To avoid excessive fumes, a sodium bisulfite solution at pH 2. rinse, and 25 volume % hydrochloric acid may be substituted for the concentrated hydrochloric acid.

Satisfactory wet chemical smear removal of through holes in copper-polyimide laminates with acrylic adhesives is available from a hot, concentrated solution of chromic acid containing 25 volume % of phosphoric acid. After rinsing, Dynachem Alkastrip 99A and an oven drying step preceding electroless copper plating improves plating adhesion to polyimide surfaces. A modified Shipley catalyst is used with Dynachem's Conditioner 101 and Dynaplate 240 A + B electroless copper to improve plating results by minimizing the swelling of acrylic.

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Pomona Division

S. A. Hays
2 March 1976

COMPARISON CHART

Old Process for Phenolic Butyral Laminates		New Process for Acrylic Laminates	
Oper. Number	Old Operation	Oper. Number	New Operation
1	N/C DRILL	1	SAME
2	X-RAY	2	SAME
3	EXAMINE	3	SAME
4A	MANUAL SCRUB	4B	AUTOMATED SCRUBBER
5	AUTOMATED RINSE DRY	5	SAME
6	RACK PANELS	6	SAME
7	SPRAY RINSE	-----------------------	
8	HOT ISOPREP 177	-----------------------	
7	SPRAY RINSE	-----------------------	
9	RUNNING WATER RINSE	-----------------------	
7	SPRAY RINSE	-----------------------	
10A	HOT NIKLAD 233P (CHROMIC ACID ETCHANT)	10B	HOT CHROMIC + PHOSPHORIC ACIDS (MODIFIED ETCHANT)
7	SPRAY RINSE	-----------------------	
6	UNRACK PANELS	-----------------------	
7	SPRAY RINSE	-----------------------	
11	RUNNING WATER RINSE	11	SAME
6	RERACK PANELS	-----------------------	
7	SPRAY RINSE	-----------------------	
12	HOT WATER RINSE	-----------------------	
7	SPRAY RINSE	-----------------------	
12	HOT WATER RINSE	-----------------------	
13	NIKLAD 220	-----------------------	
7	SPRAY RINSE	-----------------------	
6	UNRACK PANELS	-----------------------	
7	SPRAY RINSE	-----------------------	
14	RUNNING WATER RINSE	-----------------------	
15	HYDROCHLORIC ACID	-----------------------	
7	SPRAY RINSE	-----------------------	
16	RUNNING WATER RINSE	16	SAME
17	CONDITIONER 1160 (1-18 Hours)	17B	ALKASTRIP 99A (One Minute)
18	RUNNING WATER RINSE	18	SAME
5	AUTOMATED RINSE-DRY	-----------------------	
6	RERACK PANELS	-----------------------	
16	RUNNING WATER RINSE	-----------------------	
17A	CONDITIONER 1160	-----------------------	
18	RUNNING WATER RINSE	-----------------------	
19	AMMONIUM PERSULFATE	-----------------------	
20	RUNNING WATER RINSE	-----------------------	
21A	SULFURIC ACID	21B	SODIUM BISULFITE (pH 2)
22	RUNNING WATER RINSE	22	SAME
23	HYDROCHLORIC ACID (SALT OPTIONAL)	23	SAME (EXCEPT NO SALT OPTION)
24A	CATALYST	24B	SIMILAR (MODIFIED) CATALYST
25	RUNNING WATER RINSE	25	SAME
26	RUNNING WATER RINSE	-----------------------	
-----------------------		27	OVEN DRY (160°F.)
-----------------------		6	RERACK PANELS
28A	ACCELERATOR 19	28B	CONDITIONER 101
29	RUNNING WATER RINSE	29	SAME
30	DEIONIZED WATER RINSE	30	SAME
31	ELECTROLESS COPPER (DYNAPLATE 240 A + B)	31	SAME
32	NOTE ALL REMAINING OPERATIONS ARE THE SAME FOR PLATING FOLLOWING ELECTROLESS COPPER.		

ELECTROLESS COPPER LINE SIMPLIFICATION

I FOR PRINTED CIRCUITS INDUSTRY, GENERAL SUGGESTIONS

II FOR ELECTROLESS COPPER PLATING LINES, AVOIDING CHROMIUM POISIONING

III FOR FLEXIBLE CABLES USING ACRYLIC ADHESIVES, A SUCCESSFUL MULTILAYER THROUGH HOLE COPPER PLATING PROCESS INCLUDING CHROMIC ACID SMEAR REMOVAL

GENERAL SUGGESTIONS FOR PRINTED CIRCUITS INDUSTRY

1. DRILL WITH (RPM x DIA) $\div$ IPM $\approx$ CONSTANT

2. VIEW HOLES IN PROCESS WITH TILTED MICROSCOPE SUSPENDED OVER LIGHT TABLE

3. USE SIMPLE MULTI-SURFACE STRIPS FOR PROCESS CONTROL

4. USE NARROW CIRCUITRY TENSILE PEEL TESTS ON TRIM OF FINISHED PARTS

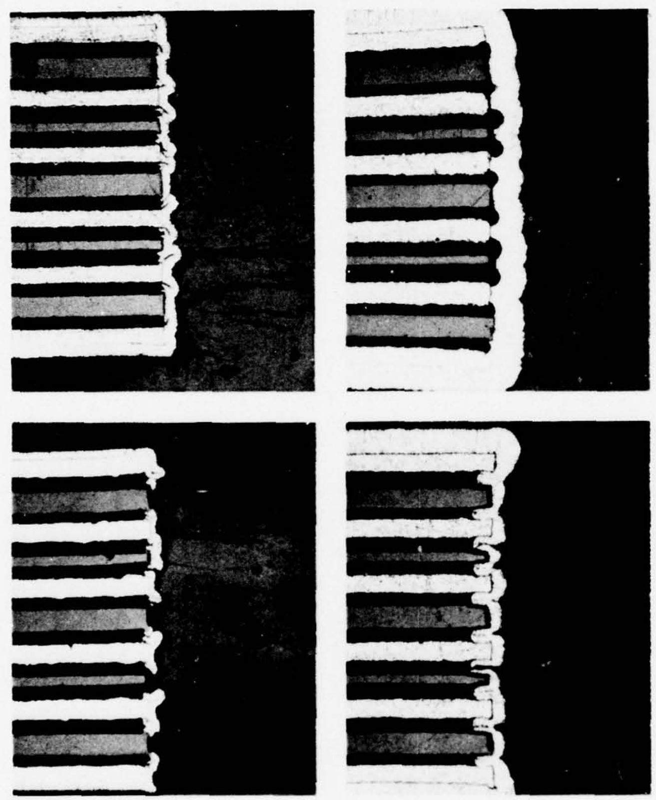
AVOIDING CHROMIUM POISONING OF ELECTROLESS COPPER PLATING LINE

1. FLEETING GHOSTS OF CHROMIUM POISONING
2. CHROMATE MODIFIES DEPOSITION OF PALLADIUM CATALYST
3. ELIMINATING AMMONIUM PERSULFATE
4. REDUCTION OF CHROMATE BY CONCENTRATED HYDROCHLORIC ACID
5. SODIUM BISULFITE AT pH 2 WITH 25% HYDROCHLORIC ACID
6. REST OF ELECTROLESS COPPER LINE NOT AFFECTED

MULTILAYER THROUGH HOLE SMEAR REMOVAL AND COPPER PLATING FOR FLEXIBLE PRINTED WIRING HARNESSES LAMINATED WITH ACRYLIC ADHESIVE

1. ACRYLIC ADHESIVES
2. COPPER – ACRYLIC – POLYIMIDE LAMINATES
3. MULTILAYER THROUGH HOLE SMEAR REMOVAL
4. ELECTROLESS COPPER PLATING LINE
5. FLEXIBLE PRINTED WIRING HARNESSES OR CABLES

TYPICAL PROBLEMS OF ACRYLIC SMEAR REMOVAL ON MULTILAYER FLEX HARNESS PLATED THRU HOLES



Note: Page xiii herein does precede this in presentation.

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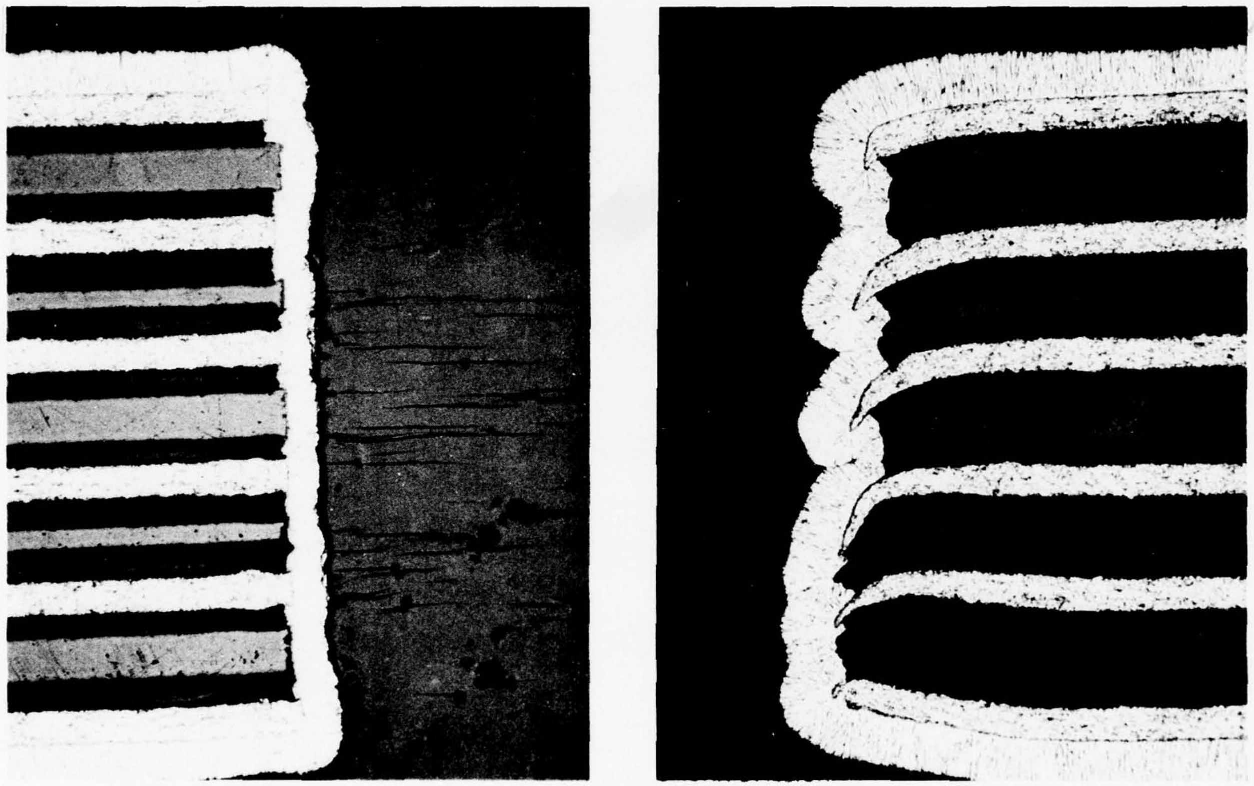
HOLES PLATED THRU AFTER SMEAR REMOVAL FROM ACRYLIC MULTILAYER FLEX HARNESS:
Drilled on Left Versus Sheared Edge on Right



WET CHEMICAL SMEAR REMOVAL FOR ACRYLIC MATERIAL

1. APPEARS SUCCESSFUL IN PILOT PLANT STAGE
2. ETCHING OF POLYIMIDE NOT ESSENTIAL
3. WHITISH RESIDUE ON ACRYLIC AS ETCHANT CONTROL
4. LIMITED SELECTION OF SUITABLE ACRYLIC ETCHANTS
5. 25% PHOSPHORIC ACID IN CHROMIC ACID ETCHANT
6. HIGHER CHROMIC ACID ETCHANT TEMPERATURES (160–220°F)

ELECTROLESS COPPER PLATING LINE FOR ACRYLICS

1. MANY CHEMICALS SHOW DETRIMENTAL AFTER-EFFECTS ON ACRYLICS

2. ALKALINE-ORGANIC ACRYLIC SURFACE TREATMENT SELECTED

3. "MODIFIED PROPRIETARY" CATALYST SOLUTION FOR ACRYLICS

4. CIRCULATING AIR OVEN-DRYING IMPROVES ADHESION

5. POST-CATALYST CONDITIONER FOR ACRYLICS

6. ELECTROLESS COPPER SOLUTION SELECTION FOR ACRYLICS

UNCLASSIFIED

ADDED COMMENTS ON PLATING LINE FOR ACRYLICS

1. ELECTROLESS NICKEL VERSUS ELECTROLESS COPPER

2. DIFFERENCES BETWEEN PLANAR AND EDGE SURFACES

3. PRODUCTION SAFETY MARGINS

4. PROCESS SIMPLIFICATION ACHIEVEMENTS

UNCLASSIFIED

COMPARISON OF PROCESSES FOR SMEAR REMOVAL AND ELECTROLESS PLATING

PRIOR	ACRYLIC
N/C DRILL	SAME
X-RAY AND EXAMINE	SAME
MANUAL SCRUB	AUTOMATED SCRUBBER
AUTOMATED RINSE-DRY	SAME
RACK PANELS	SAME
HOT ISOPREP 177	———
SPRAY RINSE	———
RUNNING WATER RINSE	———
SPRAY RINSE	———

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SECOND SLIDE OF PROCESS COMPARISON

PRIOR	ACRYLIC
CHROMIC ACID ETCHANT (HOT NIKLAD 233P)	CHROMIC ACID ETCHANT (CONTAINS 25% PHOSPHORIC ACID)
SPRAY RINSE	
UNRACK PANELS	
SPRAY RINSE	
RUNNING WATER RINSE	SAME
RERACK PANELS	
SPRAY RINSE	
HOT WATER RINSE	
SPRAY RINSE	
HOT WATER RINSE	

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THIRD SLIDE OF PROCESS COMPARISON

PRIOR	ACRYLIC
NIKLAD 220 (REDUCER)	———
SPRAY RINSE	———
UNRACK PANELS	———
SPRAY RINSE	———
RUNNING WATER RINSE	———
HYDROCHLORIC ACID	———
SPRAY RINSE	———
RUNNING WATER RINSE	SAME

UNCLASSIFIED

FOURTH SLIDE OF PROCESS COMPARISON

PRIOR	ACRYLIC
CONDITIONER 1160 (1–18 HOURS)	ALKASTRIP 99A (ONE MINUTE)
RUNNING WATER RINSE	SAME
AUTOMATED RINSE–DRY	______
RERACK PANELS	______
RUNNING WATER RINSE	______
CONDITIONER 1160	______
RUNNING WATER RINSE	______
AMMONIUM PERSULFATE	______
RUNNING WATER RINSE	______

FIFTH SLIDE OF PROCESS COMPARISON

PRIOR	ACRYLIC
SULFURIC ACID (10%)	SODIUM BISULFITE (pH 2)
RUNNING WATER RINSE	SAME
HYDROCHLORIC ACID (SALT OPTIONAL)	SAME (EXCEPT NO SALT OPTION)
CATALYST	SIMILAR (MODIFIED)
RUNNING WATER RINSE	SAME
———	*OVEN DRY (160°F)
———	RERACK FOR PLATING

*NOTE: OVEN DRYING HAS BEEN MOVED AHEAD OF FIRST CONDITIONER 101 SHOWN IN PRINTED ARTICLE. THIS ELIMINATES THREE OF FIVE STEPS PREVIOUSLY LISTED AS SPECIFIC FOR ACRYLIC PROCESS

SIXTH SLIDE OF PROCESS COMPARISON

PRIOR	ACRYLIC
RUNNING WATER RINSE	—
ACCELERATOR 19	CONDITIONER 101
RUNNING WATER RINSE	SAME
DEIONIZED WATER RINSE	SAME
ELECTROLESS COPPER (DYNAPLATE 240A + B)	SAME

NOTE: ALL REMAINING OPERATIONS ARE THE SAME FOR PLATING FOLLOWING ELECTROLESS COPPER

SUMMARY

1. CHROMIUM POISIONING OF ELECTROLESS COPPER MAY BE AVOIDED BY:
   - THOROUGH RINSING AFTER CHROMIC ACID SMEAR REMOVAL
   - ELIMINATION OF AMMONIUM PERSULFATE
   - USE OF CONCENTRATED HYDROCHLORIC ACID PRECEDING CATALYST
   - OR, SODIUM BISULFITE pH 2 PLUS 25% HYDROCHLORIC ACID
2. SATISFACTORY WET CHEMICAL SMEAR REMOVAL AND PLATING OF ACRYLIC IS AVAILABLE
   - HOT, CONCENTRATED CHROMIC-PHOSPHORIC ACID ETCHANT FOR ACRYLIC
   - ALKASTRIP 99A AND OVEN DRYING IMPROVE PLATING ADHESION
   - SELECTED CATALYST, CONDITIONER, AND ELECTROLESS COPPER FOR ACRYLICS

APPENDIX III

Additional Details to Appendix II

1. Copper Etching as a Cleaning and Deburring Procedure

Resolution of the chromium poisoning problem permits use of the available automated roller-scrubbing machines. Such use was previously prohibited on multilayer flex harnesses and hybrids, because they evidently increased chromium carry-over effects by the preferential chromium absorption on residues from Scotch-brite materials. This effect also prohibited manual scrubbing with Scotch-brite pads, so that manually operated, air-powered, rotary brush scrubbers had to be used, with pumice (or Ajax cleanser) and considerable care to avoid damage to the relatively fragile and expensive multilayer flex harnesses and hybrids. Freedom to use the automated roller scrubbers would greatly reduce processing costs (labor) by permitting automated roller scrubbing to replace the manually operated rotary power brush scrubbing with pumice which was previously specified. With some of the thinner copper laminates currently available as starting materials, extensive copper etching before plating would not be safe anyway. Therefore the two solutions (ammonium persulfate and sulfuric acid) and four tanks (including rinses) can frequently just be eliminated, saving time and money from chemicals, makeup, control, facilities, and operations. Though it seems unnecessary, if a "copper etchant" is still desired (for chemical deburring or for modifying the surface), a concentrated solution of copper chloride in hydrochloric acid is effective. Its oxidizing potential is sufficient to etch copper, but too low to oxidize the trivalent chromium. It was used successfully, but abandoned as unnecessary here.

2. Simplification of Early Development Sequence

During the development studies, a concentrated hydrochloric acid solution (HCl, as received Technical Grade) was used directly after the rinse following chromic acid smear removal (or etch-back), and again following other treatments, while the less concentrated 25 volume % HCl was used preceding the palladium catalyst. After realizing the real importance of concentrated HCl to the chromium reduction, and its relationship to the catalyst, these three steps were combined into a single concentrated hydrochloric acid step preceding the catalyst (without rinse). In spite of the obvious increase of the fume control problem, this seems like a useful simplification, and relieves much of the worry and failures, plus saving extra costs of extreme rinsing and chromium-reducing steps

For a typical multilayer epoxyglass printed wiring board smear removal process, this also eliminates the need for hot water rinses, sodium bisulfite solution, and the hydrochloric acid solution preceding the ammonium persulfate, plus their associated rinse sequences. Therefore the total savings in the process line is five solutions plus five rinse sequences.

APPENDIX III (Cont'd)

3. Fume Control

Fume control is a routine problem in all metal finishing plants. Except for the rinse tanks, almost the entire plating line deserves fume controls anyway (for hot chromic acid, hydrofluoric acid, hydrochloric acid in both dip and catalyst, numerous proprietary organic additives, formaldehyde, etc.) so the change is not great. Additional testing and high yields should permit gradual reduction of the hydrochloric acid concentration anyway, providing that its purpose is not forgotten, so that any recurrence of failures may be promptly corrected. Cooling coils in a space above the solution, covering the tank between uses, floating balls, or other effective fume control aids should be considered.

4. Sodium Bisulfite As An Alternative to Concentrated Hydrochloric Acid

Consideration of the chromate-reducing chemical reaction of sodium bisulfite indicates that it is appreciably increased with increasing acidity, though the acid effect is much less than in the chromate reduction by chloride. If we include the weaker acid effect of bisulfite versus bisulfate, this may be possibly oversimplified as:

$$3H^+ + 3HSO_3^- + 2\ CrO_3 \rightleftharpoons 3SO_4^{=} + 2\ Cr^{+++} + 3H_2O$$

This still suggests that acid is helpful for chromate reduction, but that it should not be added as sulfuric acid (since extra sulfate helps reverse the reaction). Sulfurous acid (H_2SO_3) is simply the hydrolyzed form of sulfur dioxide (SO_2) gas. SO_2 fumes, like HCl fumes, are undesirable. However, using just enough dilute hydrochloric acid to keep the pH near 2.0 provides a useful compromise, without excessive fumes of either SO_2 or HCl. The limited laboratory tests to date indicate that this slightly acidified bisulfite solution, followed by a rinse and the common "25 volume %" solution of hydrochloric acid (about 3 molar) directly preceding the palladium catalyst solution will provide much greater protection against chromium poisoning, to avoid many plating adhesion and plating void problems in plated through holes of multilayer printed wiring.

5. Sodium Hypophosphite As An Alternative to Concentrated Hydrochloric Acid

The process development indicated that either the slightly acidified, concentrated sodium bisulfite solution or a hot, dilute, sodium hypophosphite solution, with rinse, may be used prior to the less concentrated hydrochloric acid currently customary before the palladium catalyst. Bisulfite was originally selected from these two as preferable because it avoided heating costs. However, the bisulfite required control to maintain the pH near 2.0, and some precautions in control and mixing were still needed to avoid some fume problems. Additional development revealed

5. Sodium Hypophosphite As An Alternative to Concentrated Hydrochloric Acid (Cont'd)

that the sodium hypophosphite could also be effectively used at room temperature by increasing the concentration (to the 20-100 grams/liter range) without requiring close pH control. Therefore this appears to be the preferred solution to date.

6. Additional Control of Chromic Acid Etchant

An additional chromic etchant control test was developed for the other side of its operating parameter. This simply involves counting the seconds required for color removal during faucet rinsing of a flat exposed acrylic surface after chromic acid etching. Additional operating controls were found to extend chromic acid etchant life. A recovery technique to reduce chromic acid waste disposal and cost problems was also found. Vigorous attempts to eliminate the oven drying step, without limiting safety margins excessively, have not been successful. Further proof of the value of the simplified process control techniques using test coupons, as devised for this project, was obtained several times as test panels were processed under varying process parameters in attempts for still further process simplifications. The small laboratory line was operated for process development without Quality Assurance analytical control. As the solution parameters were varied during one month's testing, for example, the 1/2 x 3 inch test coupons successfully detected contaminated bisulfite and hydrochloric acid solutions, depleted catalyst solution, and chromic acid etchants outside of various operating parameters (either temperature, dilution, or depletion). Continued testing of various chromic acid formulations and temperatures, using the etch evaluation test, provided results which seem adequate for controlled acrylic etching without excessive softening or damage to the acrylic, copper, or polyimide. Test strips with exposed flat surfaces and others with drilled holes have been etched and observed. The degree of etch can be controlled in the usual manner, by time, temperature, and etchant activity. The etchant seems reasonably stable over repeated cycles of heating and cooling (which is not always true with some other extremely concentrated chromic etchant formulations).

POLYIMIDE - ACRYLIC MATERIALS FOR FLEXIBLE PRINTED CIRCUITRY

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PART I: TABLE OF CONTENTS VS. TEST SAMPLE TYPES

CONTENTS OF MATRIX ARE: TEST SAMPLE TYPES →		DOCUMENTATION AND PAGES WHERE DESCRIBED				
SECTION OR PARAGRAPH	TABLE OF CONTENTS ↓	GENERAL	MATERIAL	TWO LAYER	FOUR LAYER	PILOT LOT
	A. TEST AND EVALUATION PLAN:	M 24S-476	M 24-S-476	M 24-S 476	M 24-S-476	M 24-S-476
--	List of Figures and Tables	IV				
--	List of References	V				
--	List of Abbrev.,Acronyms, and Def.	VI-VIII				
1.0	PURPOSE OF PROGRAM	1-1				
2.0	DESCRIPTION OF FLEX. PRINT. WIRING	2-1 to 2-7				
3.0	BACKGROUND AND PREVIOUS WORK	3-1 to 3-3				
4.0	SUPPORTING SECTIONS INVOLVED	4-1 to 4-6				
5.0	OPERATIONS PLAN OUTLINE - SCHEDULE	5-1 to 5-2				
6 to 9	BREAKDOWN BY SAMPLE TYPES		SECTION 6	SECTION 7	SECTION 8	SECTION 9
6.0	MATERIAL INVESTIGATION		6-1	--	--	--
TABLE I	Table of Materials Evaluated		6-2	--	--	--
TAB. II-IV	Index of Tests		6-3 to 6-5	7.3	8.3	
6.1	Copper Clad Laminate		6-6 to 6-9	--	--	--
6.2	Insulation Sheet with Adhesive		6-9 to 6-12	--	--	--
6.3	Adhesive Film		6-13 to 6-15	--	--	--
7.1, 8.1	PROCESS DEVELOPMENT		--	7-1	8-1	--
9.0	PILOT LOT MULTILAYER FPW		--	--	--	9-1
7.1, 8.1, 9.1	Requirements		--	7-1 to 7-3	8-1 to 8-3	9-1, 9-2
7.2, 8.2	Process Development		--	7-4	8-4 to 8-6	--
7.3, 8.3, 9.2	Fabrication		--	7-4	8-6	9-2
7.4, 8.4, 9.3	Test and Evaluation		--	7-4	8-6	9-2
FIG. 7-1, 7-2	Test Pattern		--	7-5, 7-6	--	--
10.0	YIELD AND COST ANALYSIS	10-1				
11.0	REPORTS	11-1				
	B. REQUIREMENTS AND TEST METHODS		TM6-133-115	TM6-133-116	TM6-133-117	TM6-133-120
0 or 1	INTRODUCTION		2	2	2	2
0 or 1	REFERENCES		2	2	2	2
1 - 3	TEST DETAILS	SEE PART II	2-16	2-4	2-4	2-3
1 - 3	Test Index		3-5	4	4	2-3
3	Test Patterns		17	5-6	5-8	-
	C. TEST PROCEDURES		TM-133-128	TM-6-133-164	TM-6-133-168	TM-6-133-174
1.0	Introduction		4	4	4	4
1.1	Scope		4	4	4	4
1.2	Scope Limitations		4	4	4	4
1.3	Applicability		4	4	4	5
1.4	Calibration Requirements		4	4	4	5
1.5	Authorized Adjustments and Sequence		4	4	4	5
1.6	Safety Precautions		4	4	4	5
1.7	Test Environment		4	4	5	5
1.8	Definitions		5	5	5	5
2.0	Equipment and Facilities Required		5	6	6	6
3.0	Reference Documents		5	7	7	7
4.0	Test Group Definition		7	8	8	8
5.0	Sample Identification		10	9	9	9
6.0	Sample Description and Section (Manufacturer and Type)		12	10	10	10
7-63	REMAINING TEST DETAILS	SEE PART II	14-190	12-46	12-49	12-38

APPENDIX IV: CROSS INDEX OF THIS PROJECT'S DOCUMENTATION

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PART I: TABLE OF CONTENTS VS. TEST SAMPLE TYPES (Cont'd)

CONTENTS OF MATRIX ARE: TEST SAMPLE TYPES →		DOCUMENTATION AND PAGES WHERE DESCRIBED				
		GENERAL	MATERIAL	TWO LAYER	FOUR LAYER	PILOT LOT
SECTION OR PARAGRAPH	TABLE OF CONTENTS ↓					
–	D. TEST REPORTS	TM 6-133-200	TM 6-133-184	TM 6-133-186	TM 6-133-187	TM 6-133-192
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1.0	INTRODUCTION	4-5	4-9	3-4	3-5	4
1.1	Scope		4	3	3	4
1.2	Scope Limitations		4	3	3	4
1.3	Overall Test Conclusion Summary	6-7	4-7	3-4	3-4	5-6
1.4	Test Report Summary Format	6-7	8	4	5	7
1.5	Test Environment		8	4	5	7
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2.0	REFERENCE DOCUMENTS	2-3	9	5	6	8
3.0	TEST GROUP DESCRIPTION		10-12	6	7	9
4.0	SAMPLE IDENTIFICATION		13-14	7	8	10
5.0	SAMPLE DESCRIPTION (MANUFACTURER AND TYPE)		15	8	9	11
(6-27)	(TEST GROUPS:)		16-162	9-34	10-37	12-192
6.0	I Test Description & Conclusions		16	9	10	12
7.0	I Data Sheets		17-28	-	12	14-15
8.0	II Test Description & Conclusions		29	10	13	16
9.0	II Data Sheets		30-54	11-17	14-20	18
10.0	III Test Description & Conclusions		55	18	21-22	19
11.0	III Data Sheets		56-69	19-30	23-34	21
12.0	IV Test Description & Conclusions		70	31	35	22
13.0	IV Data Sheets		71-74	32-34	37	24
14.0	V Test Description & Conclusions		75	-	-	25
15.0	V Data Sheets		76-88			27
16.0	VI Test Description & Conclusions		89			28
17.0	VI Data Sheets		90-102			30
18.0	VII Test Description & Conclusions		103			31
19.0	VII Data Sheets		104-115			33
20.0	VIII Test Description & Conclusions		116			34
21.0	VIII Data Sheets		117-120			36
22.0	IX Test Description & Conclusions		121			37
23.0	IX Data Sheets		122-134			39
24.0	X Test Description & Conclusions		135			40
25.0	X Data Sheets		136-148			42
26.0	XI Test Description & Conclusions		149			
27.0	XI Data Sheets		150-162			
3.0	Discussion	8-14				
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PART II: TEST INDEX **VS. DOCUMENTATION**

SUBJECT	TEST GROUP	M24-S-476 TEST AND EVALUATION PLAN		REQUIREMENTS AND TEST METHODS		TEST PROCEDURE			TEST REPORT		
		PARA-GRAPH	PAGE	PARA-GRAPH	PAGE	PARA-GRAPH	DESCR. PAGE	DATA SHEET PAGE	PARA-GRAPH	DESCR. PAGE	DATA SHEET PAGES
A. MATERIAL INVESTIGATION		6	6-1	TM6-133-115		TM6-133-128			TM6-133 - 184		
1. COPPER CLAD LAMINATE		6.1	6-6	1.0							
Etching Copper Clad Insulation Sheet	I	6.1.1		1.1	2	7.0	14	None	6-7	16	17-19
Dielectric Strength	I	6.1.1.1		1.1.1		8.0	14	87			20
Dielectric Constant	I	.2		.2		9.0	15	88			21
Dissipation Factor	I	.3		.3		10.0	16	89			22
Volume Resistivity	I	.4		.4		11.0	17	90			23
Tensile Strength	I	.5		.5	6	12.0	18	91			24
Tear Strength (Initial)	I	.6		.6		13.0	18	92			25
Tear Strength (Propagate)	I	.7		.7		14.0	19	93			26
Moisture Absorption	I	.8	6-7	.8		15.0	20	94			27
Fungus Resistance (Vendor Cert. Only)	I	.9		.9		16.0	20	95			28
Copper Clad Insulation	II	6.1.2		1.2					8-9	29	30-35
Copper Foil	II	6.1.2.1		1.2.1		17.0	23	97			36
Copper Foil Elongation	II	.2		.2		18.0	25	98			37
Peel Strength Laminated to Treated Copper	II										-
As Received	II	.3		.3	7	19.0	26	99-100			38-39
After Solvent Exposure	II	.4		.4		20.0	27	101-106			40-45
After Solder Immersion	II	.5	6-8	.5		21.0	29	107			46
After High Temperature Exposure	II	.6		.6		22.0	30	108-109			47-48
Flexural Fatigue	II	.7		.7		23.0	31	110			49
Folding Endurance	II	.8		.8	8	24.0	32	111			50
Dimensional Stability After Etch	II	.9		.9		25.0	33	112			51-52
Above Plus Thermal Exposure	II	.10		.10		26.0	34	113-114			52-53
Curl Resistance	II	.11	6-9	.11		27.0	35	115			54
2. ADHESIVE COATED INSULATION SHEET	III	6.2		2.0					10-19	Below	56-115
As Received	III	6.2.1		2.1					10-11	55	56-59
Dielectric Strength	III	6.2.1.1		2.1.1		28.0	37	117			60
Dielectric Constant	III	.2		.2		29.0	39	118			61
Dissipation Factor	III	.3		.3	9	30.0	40	119			62
Volume Resistivity	III	.4		.4		31.0	41	120			63
Tensile Strength	III	.5		.5		32.0	42	121			64
Tear Strength, Initial	III	.6		.6		33.0	43	122			65
Tear Strength, Propagate	III	.7	6-10	.7		34.0	44	123			66
Dimensional Stability After Thermal Exposure	III	.8		.8		35.0	45	124			67
Curl Resistance	III	.9		.9		36.0	46	125			68
Folding Endurance	III	.10		.10		37.0	47	126			69

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A. MATERIAL INVESTIGATION (CONT'D)											
2. ADHESIVE COATED INSULATION SHEET (CONT'D)											
Adhesive Flow (Coated Insulation)	IV	NONE	NONE	2.1.11	10,17	38.0	49	128	12-13	70	71-74
Peel Strength When Laminated To:			6-10		10				14-19	75,89,103	76-115
Untreated Copper	V	6.2.2		2.2					14-15	75	76-79
As Laminated	V	6.2.2.1		2.2.1		39.0	51	130			80
After Solvent Exposure	V	.2		.2		40.0	52	131-136			81-86
After Solder Immersion	V	.3	6-11	.3	11	41.0	53	137			87
After High Temperature Exposure	V	.4		.4		42.0	54	138			88
Untreated Insulation Sheet	VI	6.2.3		2.3					16-17	89	90-93
As Laminated	VI	6.2.3.1		2.3.1		43.0	56	140			94
After Solvent Exposure	VI	.2		.2		44.0	57	141-146			95-100
After Solder Immersion	VI	.3		.3	12	45.0	58	147			101
After High Temperature Exposure	VI	.4	6-12	.4		46.0	59	148			102
Glass Epoxy Board	VII	6.2.4		2.4					18-19	103	104-106
As Laminated	VII	6.2.4.1		2.4.1		47.0	61	150			107
After Solvent Exposure	VII	.2		.2		48.0	62	151-156			108-113
After Solder Immersion	VII	.3		.3	13	49.0	64	157			114
After High Temperature Exposure	VII	.4		.4		50.0	65	158			115
3. ADHESIVE FILM TESTS		6.3	6-13	3.0					20-27	Below	117-162
Adhesive Flow (Film)	VIII	None	None	3.1	13,17	51.0	67	160	20-21	116	117-120
Peel Strength When Laminated To:			6-13		14				22-27	121,135,149	122-162
Untreated Copper	IX	6.3.1		3.2					22-23	121	122-125
As Laminated	IX	6.3.1.1		3.2.1		52.0	69	162			126
After Solvent Exposure	IX	.2		.2		53.0	70	163-168			127-132
After Solder Immersion	IX	.3		.3		54.0	72	169			133
After High Temperature Exposure	IX	.4		.4		55.0	73	170			134
Untreated Insulation Sheet	X	6.3.2		3.3	15				24-25	135	136-139
As Laminated	X	6.3.2.1	6-14	3.3.1		56.0	75	172			140
After Solvent Exposure	X	.2		.2		57.0	76	173-178			141-146
After Solder Immersion	X	.3		.3		58.0	78	179			147
After High Temperature Exposure	X	.4		.4		59.0	79	180			148
Glass Epoxy Board	XI	6.3.3		3.4	16				26-27	149	150-153
As Laminated	XI	6.3.3.1		3.4.1		60.0	81	182			154
After Solvent Exposure	XI	.2	6-15	.2		61.0	82	183-188			155-160
After Solder Immersion	XI	.3		.3		62.0	84	189			161
After High Temperature Exposure	XI	.4		.4		63.0	85	190			162

PART II: TEST INDEX VS. DOCUMENTATION (CONT'D)

SUBJECT	TEST GROUP	M24-S-476 TEST AND EVALUATION PLAN PARA-GRAPH	PAGE	REQUIREMENTS AND TEST METHODS PARA-GRAPH	PAGE	TEST PROCEDURE PARA GRAPH	DESCR. PAGE	DATA SHEET PAGE	TEST REPORT PARA-GRAPH	DESCR. PAGE	DATA SHEET PAGES
B. TWO LAYER FLEXIBLE PRINTED WIRING		7.0	7-1	TM6-133-116		TM6-133-164			TM6-133-186		
1. TEST SAMPLE PREPARATION (Etch, Plate, Laminate)	I	7.1				7.0	12		6	9	-
2. ELECTRICAL TESTS	II	7.1.1		1.0	2				7-8	10	11
Continuity	II	7.1.1.1		1.1		8.0	14	29-31			13-15
Insulation Resistance	II	.2		1.2		9.0	16	32			16
Dielectric Withstanding Voltage	II	.3		1.3		10.0	17	33			17
3. MECHANICAL TESTS	III	7.1.2	7-2	2.0		—	—	—	9-10	18	19
Plating Thickness of Plated Through Holes	III	7.1.2.1		2.1		11.0	19	35			21
Terminal Area Bond Strength	III	.2		2.2	3	12.0	20	36			22
Peel Strength	III	.3		2.3		13.0	21	37-41			23-27
Solderability	III	.4		2.4		14.0	22	42			28
Flexural Fatigue	III	.5		2.5		15.0	23	43			29
Folding Endurance	III	.6		2.6		16.0	24	44			30
4. ENVIRONMENTAL TESTS	IV	7.1.3	7-3	3.0		-	-	-	11-12	31	32
Thermal Shock	IV	7.1.3.1		3.1		17.0	26	(See 29)			13-15
Moisture Resistance	IV	.2		3.2	4	18.0	27	46			34
C. MULTILAYER FLEXIBLE PRINTED WIRING		8.0	8-1	TM6-133-117		TM6-133-168			TM6-133-187		
1. Test Sample Preparation (Etch, Plate, Laminate)	I	8.1				7.0	12	—	6-7	10	12
2. Electrical Tests	II	8.1.1		1.0	2	—	-	—	8-9	13	14
Continuity	II	8.1.1.1		1.1		8.0	15	32-34			16-18
Insulation Resistance	II	.2		1.2		9.0	17	35			19
Dielectric Withstanding Voltage	II	.3		1.3		10.0	18	36			20
3. MECHANICAL TESTS	III	8.1.2	8-2	2.0		-	-	-	10-11	21-22	23
Plating Thickness of Plated Through Holes	III	8.1.2.1		2.1		11.0	20	38			25
Terminal Area Bond Strength	III	.2		2.2	3	12.0	21	39			26
Peel Strength	III	.3		2.3		13.0	22	40-44			27-31
Solderability	III	.4		2.4		14.0	23	45			32
Flexural Fatigue	III	.5		2.5		15.0	24	46			33
Folding Endurance	III	.6		2.6		16.0	25	47			34
4. ENVIRONMENTAL TESTS	IV	8.1.3	8-3	3.0		-	-	-	12-13	35	35
Thermal Shock	IV	8.1.3.1		3.1		17.0	27	(See 30)			16-18
Moisture Resistance	IV	.2		3.2	4	18.0	28	49			37

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PART II: TEST INDEX VS. DOCUMENTATION (CONT'D)

SUBJECT	TEST GROUP	M24-S-476 TEST AND EVALUATION PLAN PARA-GRAPH	M24-S-476 TEST AND EVALUATION PLAN PAGE	REQUIREMENTS AND TEST METHODS PARA-GRAPH	REQUIREMENTS AND TEST METHODS PAGE	TEST PROCEDURE PARA GRAPH	TEST PROCEDURE DESCR. PAGE	TEST PROCEDURE DATA SHEET PAGE	TEST REPORT PARA-GRAPH	TEST REPORT DESCR. PAGE	TEST REPORT DATA SHEET PAGES
D. PILOT LOT MULTILAYER FLEXIBLE PRINTED WIRING		9.0	9-1	TM6-133-12G		TM6-133-174			TM6-133-192		
1. TEST SAMPLE PREPARATION AND VISUAL/DIMENSIONAL EXAMINATION	I	9.1.1		1.1	2	7.0	12	28-29	6-7	12	14-15
2. DIELECTRIC WITHSTANDING VOLTAGE	II	.2		1.2		8.0	15	30	8-9	16	18
3. CONTINUITY	III	.3		1.3		9.0	16	31	10-11	19	21
4. THERMAL SHOCK	IV	.4		1.4		10.0	18	32	12-13	22	24
5. INSULATION RESISTANCE	V	.5		1.5		11.0	19	33	14-15	25	27
6. MOISTURE RESISTANCE	VI	.6		1.6		12.0	21	34	16-17	28	30
7. TERMINAL AREA BOND STRENGTH	VII	.7		1.7		13.0	23	35	18-19	31	33
8. PEEL STRENGTH	VIII	.8	9-2	1.8	3	14.0	24	36	20-21	34	36
9. SOLDERABILITY	IX	.9		1.9		15.0	25	37	22-23	37	39
10. PLATING THICKNESS OF CONDUCTORS AND PLATED THRU HOLES	X	.10		1.10		16.0	26	38	24-25	40	42

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APPENDIX V

LIST OF ABBREVIATIONS, ACRONYMS, AND DEFINITIONS

ASTM: American Society for Testing and Materials.

"BARE" (MLF or FPW) = Multilayer flexible printed wiring (MLF) or flexible printed wiring (FPW) without protective laminated coverlay.

BONDPLY: A laminate of insulation dielectric, such as polyimide, with an adhesive coating on both sides, used between two printed wiring details (defined below) for lamination of multilayers. Additional bondply may be used in a single lamination of a more complex stack or layup for multilayer laminations.

BOND STRENGTH OR PEEL STRENGTH: Force per unit of width (such as pounds per inch) required to separate layers by a specified test method.

COVERLAY: Insulating cover sheets laminated onto one or both sides of FPW, usually with openings to expose bonding pads for connectors or other components, while insulating the remaining printed wiring to minimize chance of electrical short circuits. These are usually a laminate of an insulating sheet such as polyimide with a coating of adhesive on one side only.

DETAILS: In this limited definition for printed wiring multilayer product fabrication, "details" are the one or two layer etched laminate sheets which are laminated together to make a multilayer product.

DIELECTRIC: Electrically insulating or relatively non-conducting materials such as the polyimide insulator, acrylic adhesive, and even air-gaps.

FPW OR FPC: Flexible printed wiring = flexible printed circuitry = flex harness = "Flexprint" (Trademark name) = flexible printed cable. All of these are electronic interconnection devices with printed patterns, which may be bent readily, and which provide conductive paths separated by insulating dielectric.

GDP: GENERAL DYNAMICS, Pomona Division.

HCl: Hydrochloric Acid.

APPENDIX V (Cont'd)

IPC: Institute of Printed Circuits, the professional organization standardizing much of the "printed wiring" industry specifications, including flexible and flex-rigid hybrids, as well as the more common "rigid" printed wiring boards and multilayer boards.

M.E.K.: Methyl ethyl ketone, a common, volatile, organic solvent.

MIL: "Military" for the specification series thereof.

mil: For 0.001 inch in linear measurement.

MLF: Multilayer flexible printed wiring (more than two layers of printed conductors). The conductor layers may be ordinary printed wiring, power planes, or combinations thereof. MLF is therefore a multilayer FPW.

MLH: Multilayer hybrid. This is not a major item herein, but if MLF becomes an accepted abbreviation in the industry for "multilayer flexible printed wiring", as MLB is frequently used to designate "multilayer printed wiring board", then MLH might be used for "multilayer flexible-rigid combination hybrid", so that the series becomes: multilayer board (MLB), multilayer flex (MLF), and multilayer hybrid (MLH) to encompass the multilayers of the present printed wiring industry.

NaOH: Sodium hydroxide, very strongly basic.

NAVPRO: Naval Plant Representative Office, when used herein, refers to the one in which General Dynamics, Pomona Division is located.

NAVSEA: Naval Sea Systems Command.

N/C: "Numerically controlled" machining, such as drilling with tapes.

NRPO: Naval Regional Procurement Office.

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